



## **A User's Manual for the General Cylinder Code (GCYL)**

M. Kragalott and E.H. Newman

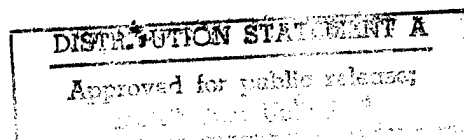
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| <b>16. Abstract (Limit: 200 words)</b><br><br>This report serves as a users manual for the "General Cylinder" (GCTL) code. GCTL is a user oriented computer code for analyzing the ( $e^{j\omega t}$ ) time harmonic TM (i.e. $E_z$ ) or TE (i.e. $H_z$ ) scattering from a general cylinder. A general cylinder is composed of open or closed perfectly conducting surfaces and/or lossy and inhomogeneous dielectric/ferrite cylinders of arbitrary cross section, as well as thin dielectric strips modeled by uniform or tapered sheet impedances. The perfectly conducting surfaces and the sheet impedance strips may contact or even penetrate the dielectric/ferrite regions. This report provides a description of the inputs and outputs of GCTL. |                      |   |  |            |                 |     |            |     |                |
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*A USER'S Manual for the General Cybernetic Code (GCYL)*

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# Chapter 1

## Introduction

This report serves as a users manual for the "General Cylinder" (GCYL) code. GCYL is a user oriented computer code for the computation of the TM or TE back or bistatic echo width of a general cylinder. A general cylinder is composed of:

1. perfectly conducting cylinders of arbitrary cross section
2. lossy and inhomogeneous dielectric and/or ferrite material cylinders of arbitrary cross section
3. electrically thin dielectric strips modeled by a sheet impedance (including tapered sheet impedances).

GCYL models an inhomogeneous, arbitrary cross section, material cylinder by a number of homogeneous material cylinders of quadrilateral cross section. The size, shape, location, and material properties of each quadrilateral cylinder are chosen so that collectively they approximate the cross section and material properties of the actual material cylinder. The arbitrary cross section perfectly conducting surfaces are modeled by a number

of flat perfectly conducting strips which are arranged to form a piecewise flat approximation to the actual (possibly curved) surface. Similarly, a number of flat sheet impedance strips are used to approximate the thin dielectric shells. A zero ohm sheet impedance strip is identical to a perfectly conducting strip. Note that the problem is two dimensional (2D) with the incident and scattered electric field being polarized parallel to the cylinder axis (i.e.  $E_z$ ) in the TM case and the incident and scattered magnetic field being polarized parallel to the cylinder axis (i.e.  $H_z$ ) in the TE case.

The theoretical basis for the GCYL code is described elsewhere [1]. In brief, the perfectly conducting and sheet impedance cylinders are represented by equivalent electric surface currents, the dielectric cylinders are represented by equivalent electric volume currents, and the ferrite cylinders are represented by equivalent magnetic volume currents [2]. For TM plane wave incidence, the electric currents are  $\hat{z}$  polarized and the magnetic currents are  $\hat{x}$  and  $\hat{y}$  polarized, whereas for TE incidence the electric currents are  $\hat{x}$  and  $\hat{y}$  polarized and the magnetic currents are  $\hat{z}$  polarized. A set of coupled integral equations for these currents are obtained by enforcing the appropriate boundary conditions at the surface of the perfectly conducting or sheet impedance cylinders, and the volume equivalence theorems in the dielectric/ferrite cylinders. The coupled integral equations are solved by the method of moments (MM) [3]. In the TM case, a pulse or piecewise constant expansion and weighting function Galerkin MM solution, identical to that developed by Wang [4], is employed on the perfectly conducting and sheet impedance surfaces. For the TE case, a sinusoidal expansion and weighting function Galerkin MM solution, identical to that developed by Richmond [6], is utilized on the perfectly conducting and sheet impedance surfaces. The equivalent electric and magnetic polarization currents repre-

representing the dielectric/ferrite cylinder are expanded in terms of quadrilateral cross section piecewise constant expansion or basis functions, with Dirac delta weighting functions being used to minimize the computer CPU time required to fill the impedance matrix [3]. The use of Dirac delta weighting functions is referred to as point matching, since one is enforcing the integral equations at a number of points at the centroid of the quadrilateral expansion functions.

The MM transforms the four coupled integral equations into a system of simultaneous linear algebraic equations, commonly referred to as a matrix equation of the form

$$[Z]I = V, \quad (1.1)$$

where  $[Z]$  is the  $N \times N$  impedance matrix ( $N$  = the total number of expansion modes) and  $V$  is the length  $N$  voltage vector. The main effort of the MM solution is to find  $[Z]$  and  $V$ . Once this is done, Equation (1.1) can be solved for the solution vector  $I$  which contains the  $N$  coefficients in the expansions for the equivalent currents. Once these currents are known, the scattered fields are simply the free space fields of these currents and thus can be computed in a straight forward manner.

The main advantage of the above described MM solution is its accuracy. It is a direct numerical solution of the exact coupled integral equations describing the scattering from the general cylinder. As such, the solution automatically contains all phenomena of the problem, including surface waves, creeping waves, edge conditions, multiple diffractions, etc. As the number of expansion functions is increased the MM solution in principle should approach the exact solution. The main limitation of the MM solution is a result of the fact that the number of expansion functions, and

hence the required computer CPU and storage, is proportional to the electric size of the cylinders. Thus, as the frequency is increased, the required computer resources increase, and at some point the MM solution becomes impractical.

GCYL models a general cylinder as a combination of basic building blocks. Chapter 2 describes these five basic building blocks. Chapter 3 describes the inputs to GCYL. That is, the methods for describing the general cylinder geometry, plus the frequency, patterns desired, etc. to GCYL. Chapter 4 further illustrates the code inputs and describes the code outputs through the use of a number of example problems. Finally, Chapter 5 describes the dimensioning of arrays in GCYL, and describes the output files PLOT, which can be used to obtain pattern plots, and GPLOT, which can be used to generate a plot of the problem geometry. Appendix A shows a subroutine CGEOM which describes the general cylinder geometry for the material coated circular cylinder of example 5 in Chapter 4. Appendix B lists the Fortran code GEOMP, which uses the output file GPLOT to generate a plot of the building block and/or mode geometry. Appendix C lists the Fortran code PATP, which reads the file PLOT and generates a pattern plot. Finally, Appendices D-H list the output files for example runs 1-5, respectively, of Chapter 4.

# Chapter 2

## GCYL Building Blocks

### 2.1 Introduction

The general cylinder geometry is described to GCYL as a combination of the following five building blocks:

1. straight sheet impedance strips, with perfectly conducting strips being the special case where the sheet impedance  $Z_s = 0 \text{ } \Omega/\square$ ,
2. quadrilateral cross section material cylinders of arbitrary complex permittivity and permeability,
3. straight sheet impedance strips coated with a quadrilateral cross section material cylinder on one side,
4. straight sheet impedance strips coated with a quadrilateral cross section material cylinder on both sides,
5. quadrilateral cross section material cylinders coated on any/all or no sides by a sheet impedance strip.

Using the above five building blocks it is possible to construct a piecewise flat approximation to an almost arbitrary cylinder. Note that each quadrilateral material cylinder may have a different complex permittivity and permeability, and that each sheet impedance strip may have a different tapered  $Z_s$ . The next sections define the sheet impedance model for a thin dielectric slab and the five GCYL building blocks.

## 2.2 Definition of Sheet Impedance

This section will describe the modeling of a thin dielectric slab by a sheet impedance strip. Figure 2.1a shows a dielectric slab of thickness  $T$  and permittivity  $\epsilon$ . The slab must be non-magnetic with free space permeability  $\mu_0$ . The sheet impedance approximations requires that two conditions be met by the dielectric slab. First, the slab must be sufficiently thin so that the electric field can be taken as essentially constant through its thickness, i.e.,

$$kT \ll 1,$$

where  $k$  is the wavenumber in the dielectric slab media. The second condition is that the polarization of the electric field in the slab should be parallel to the broad surfaces of the slab. This condition is always true for the TM polarization, but not always true for the TE polarization. In the TE plane wave incidence case, there is in general a component of electric field perpendicular to the broad surface of the slab, which violates the second condition. Thus, as the incidence wave progresses from broadside incidence to grazing incidence, the sheet impedance approximation will fail at some point toward grazing incidence. However, for dense material the electric field vector in the slab tends to align itself parallel to the broad

surface of the slab, thus making the approximation good for angles not too close to grazing incidence.

Assuming that both of the above conditions are met, then as illustrated in Figure 2.1b, the thin slab can be modeled as an infinitesimally thin strip of sheet impedance

$$Z_s = \frac{1}{j\omega(\epsilon - \epsilon_0)T}, \quad (2.1)$$

where  $\omega$  is the radian frequency, and  $\epsilon_0$  is the permittivity of free space. Thin multilayered slabs can be easily treated via the sheet impedance approximation since the sheet impedance of a multilayered slab is simply the parallel combination of the sheet impedance of each individual layer [4] (caution: reference [4] employs the  $e^{-j\omega t}$  time convention). If the thickness or permittivity of the dielectric slab are not constant, then  $Z_s$  in Equation (2.1) will not be constant. GCYL allows for constant sheet impedances, as well as sheet impedances with a linear or an exponential taper.

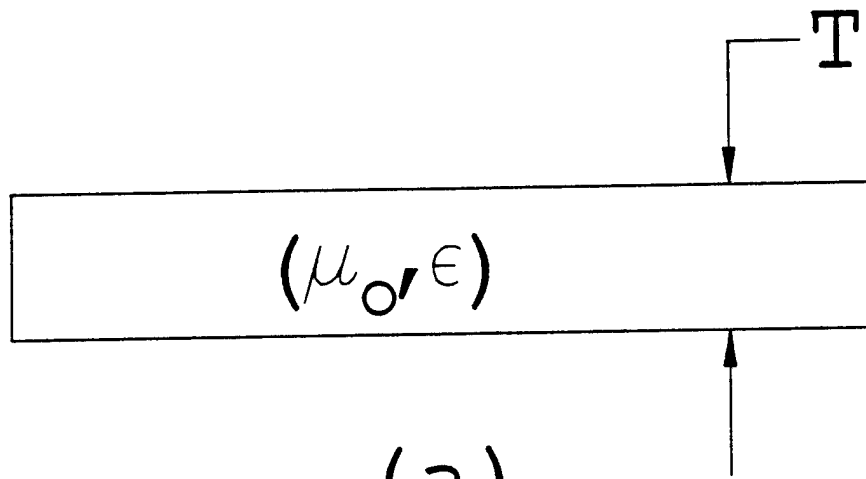
If the dielectric is lossy, with conductivity  $\sigma$ , then its complex permittivity can be written as

$$\epsilon = \left( \epsilon' - \frac{j\sigma}{\omega} \right). \quad (2.2)$$

If the dielectric is so lossy that the imaginary part of its permittivity dominates its real part, then the sheet impedance of Equation (2.1) becomes

$$Z_s \approx \frac{1}{\sigma T} \quad \frac{\sigma}{\omega} \gg \epsilon', \quad (2.3)$$

and is essentially pure real. Such a material is commonly referred to as a resistive sheet. Finally, it is important to note that an infinitesimally thin perfectly conducting strip is simply a sheet impedance strip with  $Z_s = 0$ .



(a)

$$Z_S = 1 / j\omega (\epsilon - \epsilon_0) T$$


---

(b)

Figure 2.1: (a) An electrically thin dielectric slab and (b) the equivalent sheet impedance of the slab.



## 2.3 General Cylinder Building Blocks

As described above, GCYL models a general cylinder as a combination of the five building block types shown in Figure 2.2. These five types will now be described in more detail.

### Building Block 1

Figure 2.2a shows a typical Type 1 building block, i.e., a sheet impedance strip. The sheet impedance strip is defined by the  $(x, y)$  coordinates of its endpoints, by the value of  $Z_s$  at each endpoint, and by the type of taper. If  $Z_s = 0$ , then the sheet impedance strip is a perfectly conducting strip. A particular geometry may contain several sheet impedance strips, each with a different sheet impedance. As illustrated in Figure 2.3a, the sheet impedance strips may only contact each other at their endpoints.

### Building Block 2

Figure 2.2b shows a typical Type 2 building block, i.e., a quadrilateral material cylinder. The location of the material cylinder is specified by the  $(x, y)$  coordinates of its four corner points. The quadrilateral region is assumed to contain a homogeneous dielectric/ferrite material whose complex permittivity and permeability are related to the relative permittivity and permeability and to the electric and magnetic loss tangents by

$$\begin{aligned}\epsilon &= \epsilon_r \epsilon_0 (1 - j \tan \delta_e) \\ \mu &= \mu_r \mu_0 (1 - j \tan \delta_m).\end{aligned}\tag{2.4}$$

A particular geometry may contain several quadrilateral material cylinders, each with different cross section shape and material parameters. Two quadrilateral material cylinders may not overlap, however, as illustrated in

## FIVE GTM BUILDING BLOCKS

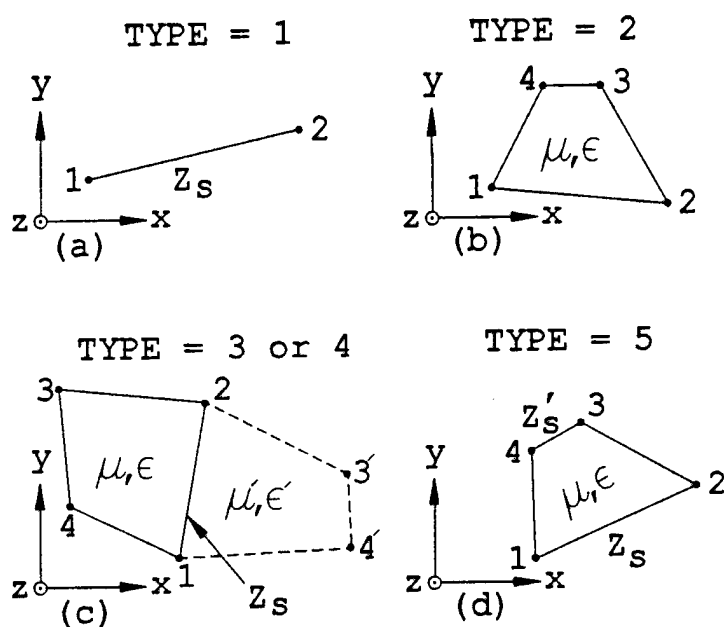


Figure 2.2: A general cylinder may be constructed from a combination of (a) sheet impedance strips, (b) quadrilateral material cylinders, and (c) sheet impedance strips coated on one or both sides by quadrilateral material cylinders, (d) quadrilateral material cylinders coated on any side(s) by sheet impedance strips.

## Permitted Block/Block Intersections

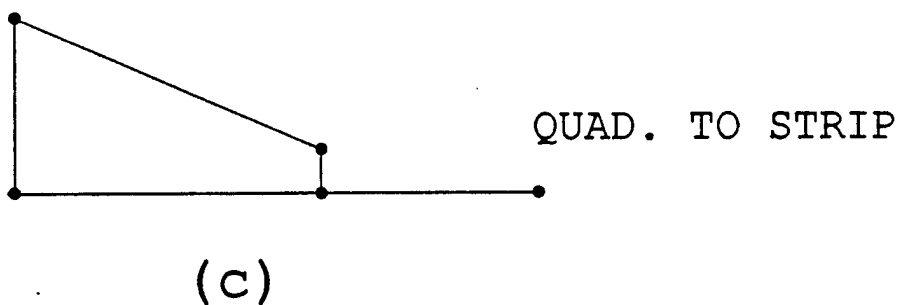
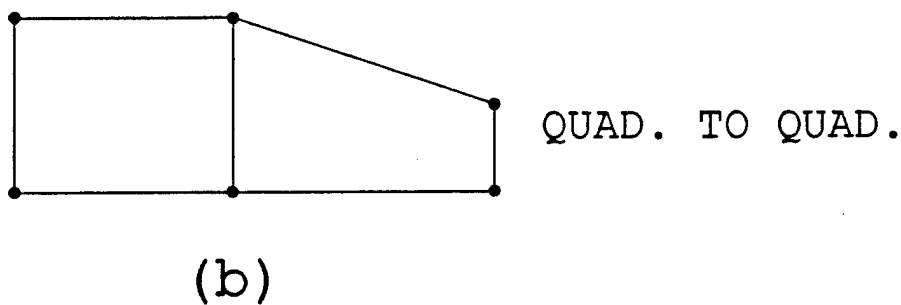
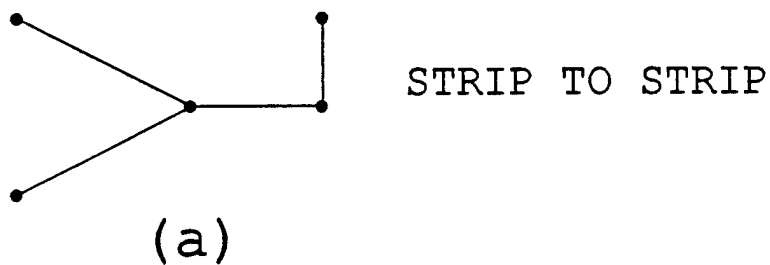


Figure 2.3: The allowed intersections between impedance strips and quadrilateral material cylinders are (a) two or more strips which intersect at their endpoints, (b) two quadrilaterals whose sides abut, and (c) the endpoint of a strip coinciding with the corner of a quadrilateral.

Figure 2.3b, two sides may abut with one another. The sheet impedance strips defined above may not contact the quadrilateral material cylinders in any way, except that the edge of a strip may coincide with the corner of a quadrilateral, as illustrated in Figure 2.3c. Impedance strips which abut a side of a quadrilateral material cylinder must be modeled with the coated impedance strips shown in Figures 2.2c,d as described below.

#### Building Blocks 3 and 4

Impedance strips which abut a side of a quadrilateral material cylinder can be modeled with the coated impedance strips shown in Figure 2.2c, and are referred to as building blocks Types 3 and 4. The location of the impedance strip is defined by the  $(x,y)$  coordinates of points 1 and 2. A quadrilateral material cylinder, with material parameters  $(\mu, \epsilon)$ , is located in the region defined by the points 1,2,3,4. Building block Type 3 involves the impedance strip 1,2 and quadrilateral material cylinder 1,2,3,4. Building block Type 4 involves the impedance strip 1,2, the quadrilateral material cylinder 1,2,3,4, and in addition, a second quadrilateral material cylinder with parameters  $(\mu', \epsilon')$  located in the region defined by the points 1,2,3',4'. This region is shown by the dashed line in Figure 2.2c. Building block Type 3 is intended for use in describing a material cylinder which is coated on one side by a perfectly conducting or a sheet impedance surface. Building block Type 4 is intended for use when a perfectly conducting or a sheet impedance surface penetrates a material cylinder.

#### Building Block 5

Building block Type 5 is shown in Figure 2.2d and consists of a quadrilateral material cylinder with sheet impedance strips located on any side desired. Thus, the quadrilateral region may be a pure material cylinder

like a Type 2 building block, a coated strip like a Type 3 building block, or any other combination of sheet impedance strips in edge contact with the material cylinder. Building block Type 5 is intended for use when a material cylinder is coated on more than one side by perfectly conducting or sheet impedance surfaces. A particular geometry may contain several of the material coated impedance strips of Figures 2.2c,d.

The rules as to how coated impedance strips may contact other building blocks of the general cylinder are the same as for simple impedance sheets and quadrilateral material cylinders, i.e.,

- two strips may only contact at their endpoints (Figure 2.3a),
- two quadrilateral material cylinders may not overlap, but may have their sides abut (Figure 2.3b),
- a simple strip may not penetrate or abut a quadrilateral material cylinder, except that a strip endpoint may coincide with a quadrilateral corner (Figure 2.3c.)

In summary, GCYL constructs a general cylinder from a combination of the building blocks shown in Figure 2.2a-d. In particular, the five types of building blocks are:

1. Type 1: a simple sheet impedance strip as seen in Figure 2.2a
2. Type 2: a quadrilateral material cylinder as seen in Figure 2.2b
3. Type 3: a sheet impedance strip coated on one side by a quadrilateral material cylinder as seen by the solid lines in Figure 2.2c

4. Type 4: a sheet impedance strip coated on both sides by a quadrilateral material cylinder as seen by the solid plus dashed lines in Figure 2.2c
5. Type 5: a quadrilateral material cylinder coated on any side(s) by sheet impedance strips as seen in Figure 2.2d.

It is important to distinguish between the building blocks defined by the user, and the MM expansion modes defined by GCYL. The building blocks are physical matter which are arranged to approximate the geometry of the actual cylinder. There is no limitation on their size. For example, it is legitimate to define a sheet impedance strip  $100\lambda$  in width. GCYL segments the building blocks into the MM modes, whose maximum dimension is typically  $0.1$  to  $0.25\lambda$ . Thus, a particular problem may involve a relatively few building blocks, defined by the user, but thousands of MM modes, defined by GCYL. In this way, the user is concerned only with the physical modeling of the cylinder, and not with the more numerous and complicated MM expansion modes. Also, from the user's standpoint, the definition of the building blocks is frequency independent since GCYL will automatically segment the building blocks into more (fewer) modes as the frequency is increased (decreased).

## Chapter 3

# Command Inputs

In order to compute the scattering from a general cylinder it is necessary to define the cylinder geometry (in terms of the five building blocks shown in Figure 2.2) plus other information such as the type of pattern desired, the frequency, the polarization (TM or TE), etc. This information is specified to GCYL by 17 command inputs. A typical command has the form:

CMD: COMMAND DESCRIPTION

Parameter List 1

Parameter List 2

where CMD is the command. All commands are three character strings in length. Following the command is a colon (:) and then a brief description of the command. The colon and the description are ignored by the code. They are included if the user wishes to make the input file easier to read. Some commands have a number of associated input parameters. In these cases, one to five lines of these parameters are listed immediately following the command. The commands and their associated parameter lists are read

on logical unit 5 from a file normally called INF.DAT. All commands are input in subroutine INPUTS.

Not all commands need be executed on a given run. The only command which must be executed is the END command, which indicates the end of the command inputs. Some input parameters have default values. The default value is the value a parameter is assigned if the command which defines that parameter is not executed. The default value, if any, is shown in parentheses following the parameter list. For example, if a parameter list is shown as

P1 P2 P3  
(0.0) (1.0) (-1.0)      (Defaults)

then parameter P1 has a default value of 0.0, parameter P2 has a default value 1.0, and P3 has a default value of -1.0.

Below is a list of the GCYL commands. They are presented in alphabetical order. However, unless specifically indicated they can be executed in any order.

### **3.1 COMMAND ACU: ACCURACY PARAMETERS**

Command ACU sets the values of four parameters which control the accuracy of the numerical integrations and summations in the code.

Form of the command:

ACU: ACCURACY PARAMETERS



INTM INT SEGM SEGC

(16) (6) (.15) (.15) (Defaults)

**INTM** = the number of integration points per quadrilateral side for self-impedance elements.

**INT** = the number of integration segments per conductor segment.

**SEGM** = the maximum length of a quadrilateral side (in material wavelengths).

**SEGC** = the maximum length of a conductor segment (in free space wavelengths).

As INTM and INT are increased, and SEGM and SEGC are decreased, the accuracy of the solution increases, although at a cost of increased CPU time. In addition, the storage requirements increase as SEGM and SEGC decrease, since this will increase the number of MM modes.

### 3.2 COMMAND BT1: BLOCK TYPE 1

Command BT1 sets the values of eight parameters which determine the geometry and sheet impedance of a Type 1 building block. The definition of the geometry and sheet impedance for a Type 1 building block is given in Figure 2.2. The BT1 command may be used several times in an input file, i.e., once for each Type 1 building block.

Form of the command:

BT1: BLOCK TYPE 1

X1 Y1 X2 Y2

IZSHTR IZSHTI ZSHT1 ZSHT2

**X1,Y1** =  $(x,y)$  coordinates of point 1 of the impedance strip (meters).

**X2,Y2** =  $(x,y)$  coordinates of point 2 of the sheet impedance strip (meters).

**IZSHTR** = indicator for the taper type of the real part of the sheet impedance.

= 1 implies a linear taper.

= 2 implies an exponential taper.

**IZSHTI** = indicator for the taper type of the imaginary part of the sheet impedance.

= 1 implies a linear taper.

= 2 implies an exponential taper.

**ZSHT1** = the complex value of the sheet impedance at point 1 ( $\Omega/\square$ )

**ZSHT2** = the complex value of the sheet impedance at point 2 ( $\Omega/\square$ )

GCYL allows for independent tapering of the real and imaginary parts of the sheet impedance. This would be useful in modeling a tapered resistive strip (the real part of  $Z_s$ ) on a lossless dielectric substrate (the imaginary part of  $Z_s$ ). Note that ZSHT1 and ZSHT2 are complex numbers.

### 3.3 COMMAND BT2: BLOCK TYPE 2

Command BT2 sets the values of 12 parameters which determine the geometry and material composition of a Type 2 building block. The geometry

and the material parameters for a Type 2 block is described in Figure 2.2. The BT2 command may be used several times in a given input file, i.e., once for each Type 2 building block.

Form of the command:

```
BT2: BLOCK TYPE 2
X1 Y1 X2 Y2 X3 Y3 X4 Y4
ER TDE UR TDM
```

$XN, YN = (x, y)$  coordinates of point N of the quadrilateral region (meters).

**ER** = relative permittivity of material.

**TDE** = electric loss tangent.

**UR** = relative permeability of material.

**TDM** = magnetic loss tangent.

### 3.4 COMMAND BT3: BLOCK TYPE 3

BT3 sets the values of 16 parameters which determine the geometry, material composition and sheet impedance of a Type 3 building block. The description of a Type 3 building block is given in Figure 2.2. The BT3 command may be used several times in a given input file, i.e., once for each Type 3 building block.

Form of the command:

BT3: BLOCK TYPE 3

X1 Y1 X2 Y2 X3 Y3 X4 Y4

ER TDE UR TDM

IZSHTR IZSHTI ZSHT1 ZSHT2

$X_N, Y_N = (x, y)$  coordinates of point N of the quadrilateral region 1,2,3,4  
(meters).

ER = relative permittivity of material.

TDE = electric loss tangent.

UR = relative permeability of material.

TDM = magnetic loss tangent.

IZSHTR = indicator for the taper type of the real part of the sheet  
impedance.

= 1 implies a linear taper.

= 2 implies an exponential taper.

IZSHTI = indicator for the taper type of the imaginary part of the sheet  
impedance.

= 1 implies a linear taper.

= 2 implies an exponential taper.

ZSHT1 = the complex value of the sheet impedance at point 1 ( $\Omega/\square$ )

ZSHT2 = the complex value of the sheet impedance at point 2 ( $\Omega/\square$ )

### 3.5 COMMAND BT4: BLOCK TYPE 4

BT4 sets the values of 24 parameters which determine the geometry, material composition and sheet impedance of a Type 4 building block. The description of a Type 4 building block is given in Figure 2.2. The BT4 command may be used several times in a given input file, i.e., once for each Type 4 building block.

Form of the command:

```
BT4: BLOCK TYPE 4
X1 Y1 X2 Y2 X3 Y3 X4 Y4
ER TDE UR TDM
X3P Y3P X4P Y4P
ERP TDEP URP TDMP
IZSHTR IZSHTI ZSHT1 ZSHT2
```

$XN, YN = (x, y)$  coordinates of point N of the quadrilateral region I (meters).

**ER** = relative permittivity of quadrilateral region I.

**TDE** = electric loss tangent of quadrilateral region I.

**UR** = relative permeability of quadrilateral region I.

**TDM** = magnetic loss tangent of quadrilateral region I.

$XNP, YNP = (x, y)$  coordinates of point  $N = 3'$  or  $4'$  of quadrilateral region II.

**ERP** = relative permittivity of quadrilateral region II.

**TDEP** = electric loss tangent of quadrilateral region II.

**URP** = relative permeability of quadrilateral region II.

**TDMP** = magnetic loss tangent of quadrilateral region II.

**IZSHTR** = indicator for the taper type of the real part of the sheet impedance.

= 1 implies a linear taper.

= 2 implies an exponential taper.

**IZSHTI** = indicator for the taper type of the imaginary part of the sheet impedance.

= 1 implies a linear taper.

= 2 implies an exponential taper.

**ZSHT1** = the complex value of the sheet impedance at point 1 ( $\Omega/\square$ )

**ZSHT2** = the complex value of the sheet impedance at point 2 ( $\Omega/\square$ )

Referring to Figure 2.2, region I is the quadrilateral cylinder 1,2,3,4, while region II is the quadrilateral cylinder 1,2,3',4'.

### 3.6 COMMAND BT5: BLOCK TYPE 5

BT5 sets the values of 18 parameters which determine the geometry, material composition and sheet impedance of a Type 5 building block. The description of a Type 5 building block is given in Figure 2.2. The BT5 command may be used several times in a given input file, i.e., once for each Type 5 building block.

Form of the command:

BT5: BLOCK TYPE 5  
X1 Y1 X2 Y2 X3 Y3 X4 Y4  
ER TDE UR TDM  
IZSHTR IZSHTI ZSHT1 ZSHT2 ZSHT3 ZSHT4  
IZ12 IZ23 IZ34 IZ41

$XN, YN = (x, y)$  coordinates of point N of the quadrilateral region (meters).

ER = relative permittivity of material.

TDE = electric loss tangent.

UR = relative permeability of material.

TDM = magnetic loss tangent.

IZSHTR = indicator for the taper type of the real part of the sheet impedance.

= 1 implies a linear taper.

= 2 implies an exponential taper.

IZSHTI = indicator for the taper type of the imaginary part of the sheet impedance.

= 1 implies a linear taper.

= 2 implies an exponential taper.

ZSHT1 = the complex value of the sheet impedance at point 1 ( $\Omega/\square$ )

ZSHT2 = the complex value of the sheet impedance at point 2 ( $\Omega/\square$ )

**ZSHT3** = the complex value of the sheet impedance at point 3 ( $\Omega/\square$ )

**ZSHT4** = the complex value of the sheet impedance at point 4 ( $\Omega/\square$ )

**IZ12** = 0 if there is no sheet impedance strip on side12 of quadrilateral region 1,2,3,4.

= 1 if there is a sheet impedance strip on side12 of quadrilateral region 1,2,3,4.

**IZ23** = 0 if there is no sheet impedance strip on side23 of quadrilateral region 1,2,3,4.

= 1 if there is a sheet impedance strip on side23 of quadrilateral region 1,2,3,4.

**IZ34** = 0 if there is no sheet impedance strip on side34 of quadrilateral region 1,2,3,4.

= 1 if there is a sheet impedance strip on side34 of quadrilateral region 1,2,3,4.

**IZ41** = 0 if there is no sheet impedance strip on side41 of quadrilateral region 1,2,3,4.

= 1 if there is a sheet impedance strip on side41 of quadrilateral region 1,2,3,4.

### **3.7 COMMAND COM: COMMENT COMMAND**

Command COM allows the user to make a comment near the top of the output file which is descriptive of the problem being run. Thus, if the user was running a dielectric coated circular cylinder, then a comment



such as 'DIELECTRIC COATED CIRCULAR CYLINDER' may be an appropriate title to describe the output file.

Form of the command:

COM: COM COMMAND  
DESCRIPTION OF RUN

### **3.8 COMMAND END: END OF DATA COMMAND**

Command END indicates the end of the input data file. The last line in the input file must always be the END command.

Form of the command:

END: END COMMAND

### **3.9 COMMAND FMZ: FREQUENCY IN MEGAHERTZ**

Command FMZ sets the frequency of the incident wave in Mhz.

Form of the command:

FMZ: FREQUENCY  
FMZ  
(300.0)            (Default)

**FMZ** = frequency in megahertz

Note that if the FMZ command is not executed, the default frequency is 300 Mhz, i.e.,  $\lambda = 1$  meter.

### 3.10 COMMAND INF: INTERNAL FIELDS

The INF command causes GCYL to compute and print a list of the internal fields at the centroid of the quadrilateral cells which comprise the MM expansion modes for the dielectric/ferrite cylinders. The INF command can only be executed if a bistatic pattern is specified in the SCP command (IPAT = 1). The excitation is by a wave incident from  $\phi = \text{PHID}$  degrees, with PHID defined in the SCP command.

Form of the command:

INF: INTERNAL FIELDS

Once the equivalent volume polarization currents have been determined, the volume equivalence theorems [2] can be used to compute the internal fields. This computation is extremely straight-forward, and requires practically no CPU time. Thus, the user should not hesitate to use the INF command if there is an interest in the internal fields. Note that GCYL can not compute the internal magnetic fields of a pure dielectric material ( $\mu = \mu_0$ ) or the internal electric fields of a pure magnetic material ( $\epsilon = \epsilon_0$ ). In these cases, the internal fields are shown as zero.

### 3.11 COMMAND MDG: MODE GEOMETRY

GCYL always outputs the geometry of the building blocks defined by the user. GCYL then segments the building blocks into the MM modes. The detailed mode geometry is only printed if the MDG command is executed. Note that this can result in a fairly large output if the cylinder is electrically large.

Form of the command:

MDG: MODE GEOMETRY

### 3.12 COMMAND POL: POLARIZATION

Command POL determines whether the incident plane wave is a transverse electric (i.e.  $H_z$ ) wave or a transverse magnetic (i.e.  $E_z$ ) wave.

Form of the command:

POL: POLARIZATION

NPOL

(0) (Default)

**NPOL** = indicator for polarization type.

0 for TM problem.

1 for TE problem.

Note that if the NPOL command is not executed the default polarization is TM.

### 3.13 COMMAND PRC: PRINT COMMANDS

GCYL always provides a printout summarizing the problem geometry and other input parameters. However, there are cases where a user wishes a direct echoing of the exact input parameters for each command. If the PRC command is executed, GCYL will print the inputs corresponding to each command, *immediately following that command*. Only commands following the PRC command will be printed. Thus, if the PRC command is used, normally it will be the first command of the input file.

Form of the command:

PRC: PRINT COMMANDS

### 3.14 COMMAND RUN: RUN COMMAND

MM codes, such as GCYL, often require long and complicated input files, and also large amounts of CPU time to perform the MM computations. When running GCYL on a complicated geometry, it is expected that the user may need several runs just to get the input file correct. It is extremely wasteful to perform the expensive MM computations if one is not sure that the input file is correct. If the RUN command *is not* executed, then GCYL will simply read the input file, print out a description of the problem, and then stop, i.e., no MM computations will be made. These runs typically require only about a second of CPU time. When the user is confident that the input file is correct, then the RUN command is added to the input file and GCYL will proceed to make the desired MM computations.

Form of the command:

RUN: RUN COMMAND

### 3.15 COMMAND SCP: SCATTERING PATTERN

Command SCP defines the parameters of the plane wave scattering pattern. GCYL can compute either a back or bistatic scattering pattern. In a backscatter pattern the angle of the incident wave is identical to that of the scattered wave. A pattern is obtained by varying the angle from 0 to 360 degrees. In a bistatic pattern the angle of the incident wave is fixed, and the angle of the scattered wave is varied from 0 to 360 degrees.

Form of the command:

SCP: SCATTERING PATTERN

IPAT PHID STEP

(1) (0.0) (5.0) (Defaults)

**IPAT** = indicator for pattern type.

0 for backscatter pattern.

1 for bistatic pattern.

**PHID** = for a bistatic pattern, the cylindrical  $\phi$  angle between the positive  $x$  axis and the opposite direction of the incident wave; for backscatter patterns this parameter is ignored (degrees).

**STEP** = incremental angle between scattering observations. (degrees)

Note that all patterns go from 0 to 360 degrees.

### **3.16 COMMAND SUB: SUBROUTINE GENERATED INPUT**

In many problems, the longest and most complicated part of the input file is the definition of the building blocks which approximate the actual cylinder geometry. Some cylinder geometries may require hundreds of building blocks, which in turn would require hundreds of the BT1-BT5 commands. If the cylinder geometry has a reasonably simple geometric description, in these cases, the user should consider writing an external driver code, whose output would be a file containing the BT1-BT5 commands. An alternate method for defining the building block geometry is provided by the SUB command. If the SUB command is executed, then the building block geometry is to be generated by a Fortran subroutine CGEOM written by the user. The window of subroutine CGEOM is fixed and is described in Appendix A. If the SUB command is used, then the commands BT1-BT5 can not be used, although all other commands of subroutine INPUT must be used to specify other parameters of the problem.

Form of the command:

#### **SUB: SUBROUTINE GENERATED INPUT**

In summary, if the SUB command is executed, then the building block geometry is to be generated by the user written Fortran subroutine, CGEOM rather than by the BT1-BT5 commands. Subroutine CGEOM is described in Section 3.18.

### 3.17 COMMAND WRI: WRITE INDICATORS

Command WRI is used to obtain printouts of the currents, right hand side vector, and impedance matrix.

Form of the command:

WRI: WRITE INDICATORS

IZWR ICWR

(0) (0) (Defaults)

**IZWR** = indicator to print out impedance matrix.

0 do not print out impedance matrix.

1 print out impedance matrix.

**ICWR** = indicator to print out right hand side vector and currents.

0 do not print current or solution vector

1 print current or solution vector.

Caution should be exercised in using the WRI command. Setting IZWR to 1 will result in  $N^2$  lines of output, where  $N$  is the number of unknowns in the MM solution. Setting ICWR to 1 will result in  $2N$  lines of output for every angle in a backscatter pattern.

### 3.18 Subroutine CGEOM

This section will describe the user generated Fortran subroutine CGEOM. If the SUB command is evoked in the INF.DAT file, then the building blocks

comprising the cylinder geometry are defined in subroutine CGEOM. However, the user must specify all other non-building block information in the INF.DAT input file. The window parameters of subroutine CGEOM always have the exact form as shown in Appendix A. A user may have several subroutine CGEOM's for defining various cylinder geometries. All are called CGEOM and all have the window parameters shown in Appendix A. A particular subroutine CGEOM is selected by linking that subroutine CGEOM with GCYL.

When GCYL is linked to form an executable program, a subroutine CGEOM must be included or a link error stating that module CGEOM can not be found will be generated. Thus, a user who does not wish to employ the subroutine CGEOM must either comment out (by placing a C in column one) the call to CGEOM in the GCYL main program, or include a dummy subroutine CGEOM such as the one shown in Appendix A.

### **3.18.1 CGEOM Window Inputs and Outputs**

Referring to Appendix A, window parameters FMHZ, SEGM, and SEGC are inputs to CGEOM and are specified by commands FMZ and ACU respectively, while the remaining parameters are outputs and must be defined in subroutine CGEOM. All of the window parameters in CGEOM have been defined in Section 3.18, however, for convenience they will also briefly be defined here. The reader is referred to Figure 2.2 for the geometry of the five types of building blocks.



### Inputs to Subroutine CGEOM

**FMHZ** = frequency in Megahertz.

**SEGM** = maximum side length in material wavelengths for segmenting the material building blocks into the MM expansion functions.

**SEGC** = maximum segment size in free space wavelengths for segmenting the TYPE 1 building blocks into the MM expansion functions.

### Outputs from Subroutine CGEOM

**NGEN** = the number of building blocks.

**ITYP(I)** = the block type for building block I.

= 1 implies a sheet impedance strip from points 1 to 2.

= 2 implies a quadrilateral material cylinder in the region 1,2,3,4.

= 3 implies a sheet impedance strip from points 1 to 2 coated with a material in the quadrilateral region 1,2,3,4.

= 4 implies a sheet impedance strip from points 1 to 2 coated with a material in the quadrilateral region 1,2,3,4 and in the quadrilateral region 1,2,3',4'.

= 5 implies a quadrilateral material cylinder in the region 1,2,3,4 coated on any side(s) by sheet impedance strips.

**X1(I), Y1(I)** = (x,y) coordinates in meters of point 1 of building block I.

**X2(I), Y2(I)** = (x,y) coordinates in meters of point 2 of building block I.

$X3(I), Y3(I) = (x, y)$  coordinates in meters of point 3 of building block I.

$X4(I), Y4(I) = (x, y)$  coordinates in meters of point 4 of building block I.

$X3P(I), Y3P(I) = (x, y)$  coordinates in meters of point 3' of building block I.

$X4P(I), Y4P(I) = (x, y)$  coordinates in meters of point 4' of building block I.

$IZSHTR(I)$  = indicator for the type of taper of the real part of sheet impedance in building block I.

= 1 implies a real part of sheet impedance which tapers linearly from  $ZSHT1(I) \Omega/\square$  at point 1 to  $ZSHT2(I) \Omega/\square$  at point 2, and similarly on any strip m,n.

= 2 implies a real part of sheet impedance which tapers exponentially from  $ZSHT1(I) \Omega/\square$  at point 1 to  $ZSHT2(I) \Omega/\square$  at point 2, and similarly on any strip m,n.

$IZSHTI(I)$  = indicator for the type of taper of the imaginary part of sheet impedance in building block I.

= 1 implies an imaginary part of sheet impedance which tapers linearly from  $ZSHT1(I) \Omega/\square$  at point 1 to  $ZSHT2(I) \Omega/\square$  at point 2, and similarly on any strip m,n.

= 2 implies an imaginary part of sheet impedance which tapers exponentially from  $ZSHT1(I) \Omega/\square$  at point 1 to  $ZSHT2(I) \Omega/\square$  at point 2, and similarly on any strip m,n.

**ZSHT1(I)** = the complex sheet impedance in  $\Omega/\square$  at point 1 in building block I.

**ZSHT2(I)** = the complex sheet impedance in  $\Omega/\square$  at point 2 of building block I.

**ZSHT3(I)** = the complex sheet impedance in  $\Omega/\square$  at point 3 of building block I.

**ZSHT4(I)** = the complex sheet impedance in  $\Omega/\square$  at point 4 of building block I.

**IZ12(I)** = 0 if there is no sheet impedance strip on side12 of quadrilateral region 1,2,3,4 of building block I.  
= 1 if there is a sheet impedance strip on side12 of quadrilateral region 1,2,3,4 of building block I.

**IZ23(I)** = 0 if there is no sheet impedance strip on side23 of quadrilateral region 1,2,3,4 of building block I.  
= 1 if there is a sheet impedance strip on side23 of quadrilateral region 1,2,3,4 of building block I.

**IZ34(I)** = 0 if there is no sheet impedance strip on side34 of quadrilateral region 1,2,3,4 of building block I.  
= 1 if there is a sheet impedance strip on side34 of quadrilateral region 1,2,3,4 of building block I.

**IZ41(I)** = 0 if there is no sheet impedance strip on side41 of quadrilateral region 1,2,3,4 building block I.  
= 1 if there is a sheet impedance strip on side41 of quadrilateral region 1,2,3,4 building block I.

**ER(I)** the relative dielectric constant of the material in the quadrilateral region 1,2,3,4 of building block I.

**TDE(I)** the electric loss tangent of the material in the quadrilateral region 1,2,3,4 of building block I.

**UR(I)** the relative permeability of the material in the quadrilateral region 1,2,3,4 of building block I.

**TDM(I)** the magnetic loss tangent of the material in the quadrilateral region 1,2,3,4 of building block I.

**ERP(I)** the relative dielectric constant of the material in the quadrilateral region 1,2,3',4' of building block I.

**TDEP(I)** the electric loss tangent of the material in the quadrilateral region 1,2,3',4' of building block I.

**URP(I)** the relative permeability of the material in the quadrilateral region 1,2,3',4' of building block I.

**TDMP(I)** the magnetic loss tangent of the material in the quadrilateral region 1,2,3',4' of building block I.

**IDIE** indicator for dielectric material.

**IFER** indicator for ferrite material.

If an element in one of the above arrays is meaningless, then it does not have to be defined. For example, if  $ITYP(J) = 1$ , then building block J is a simple impedance strip, and  $X3(J)$ ,  $Y3(J)$ ,  $X4(J)$ ,  $Y4(J)$ ,  $ER(J)$ ,  $TDE(J)$ , etc., need not be defined. If the parameter would not be input, then it need not be defined in CGEOM.

### 3.18.2 CGEOM Example - A Coated Circular Cylinder

The writing of subroutine CGEOM will now be illustrated by the example of the coated perfectly conducting circular cylinder shown in Figure 3.1a. The perfectly conducting circular cylinder is of radius  $A$ , while the coating has inner radius  $A$  and outer radius  $B$ . The coating material is homogeneous with parameters  $(\mu, \epsilon)$ . Below we will describe a subroutine CGEOM which defines a number of building blocks that approximate the coated circular cylinder.

The GCYL model of the coated circular cylinder is shown in Figure 3.1b. For purposes of illustration, the circular cylinders of radius  $A$  and  $B$  are approximated by 12 sided regular polygons. As described below, the actual number of sides for a specific cylinder will be a function of the outer radius,  $B$ , the wavelength in the material coating, and SEGM. By connecting the corners of the inner and outer polygons, a number (i.e.,  $NGEN = 12$ ) of quadrilateral regions are created which will be the building blocks representing the coated cylinder. The building blocks are numbered counterclockwise from the  $x$  axis. The four corners of the  $N^{th}$  building block are shown. The building blocks will be of Type 3, i.e., coated on one side only, with a zero sheet impedance from points 1 to 2.

Appendix A shows a subroutine CGEOM which defines the building blocks representing the coated cylinder geometry. Lines 62,63 define the inner and outer radii of the cylinder, while the relative permittivity, permeability, and loss tangents of the coating are specified in lines 65-70. Although here we define the geometry of the cylinder via Fortran statements, the above parameters could easily be read from an input file.

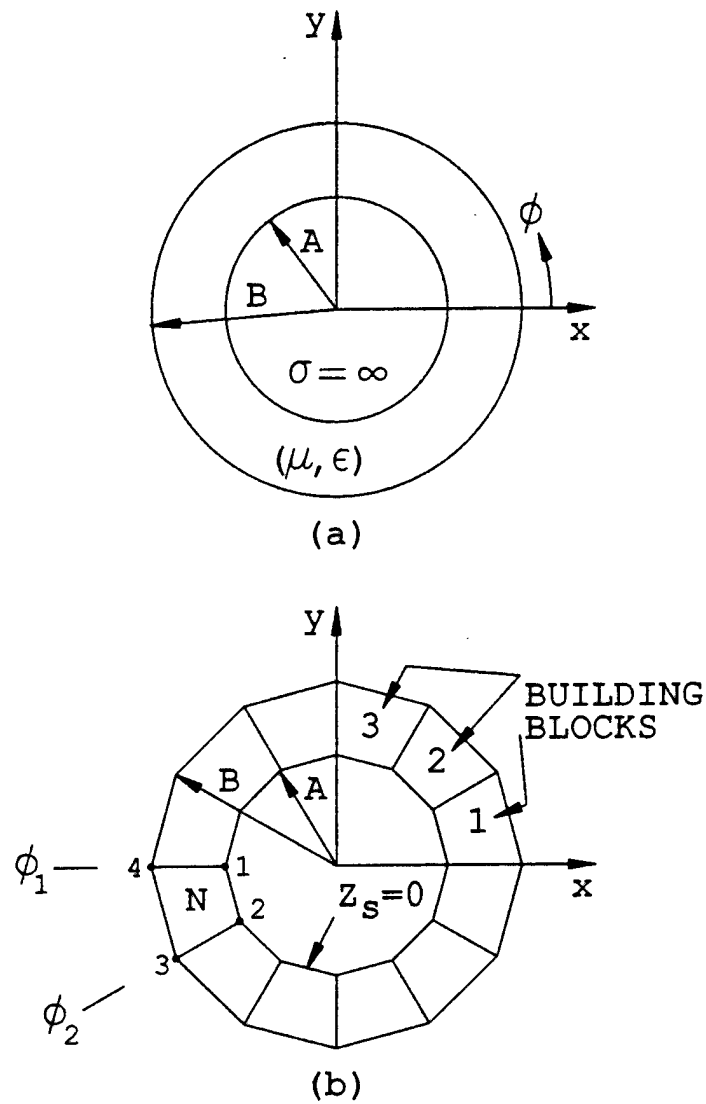


Figure 3.1: (a) Geometry for a material coated perfectly conducting circular cylinder, and (b) the cylinder model by  $NGEN = 12$  building blocks of Type 3.

We wish to approximate the circular cross section cylinder by regular polygons such that the side length of the outer polygon does not exceed SEGM material wavelengths at the frequency  $f = \text{FMHZ}$  megahertz. Line 73 computes the wavelength in the coating material, and line 75 computes  $\text{SMAX} =$  the maximum side length of the outer polygon. Line 79 computes the angular sector,  $\text{DPHI}$ , for a side of length  $\text{SMAX}$  of a regular polygon of radius  $B$ . Since the entire polygon spans  $2\pi$  radians,  $\text{NSIDES} =$  the number of sides in the polygon will be the first integer larger than  $2\pi/\text{DPHI}$ .  $\text{NSIDES}$  is computed in line 82-84. Lines 83,84 insure that  $\text{NSIDES}$  is an even number greater than or equal to 4. Line 85 recomputes  $\text{DPHI} =$  the angular sector of one side of the  $\text{NSIDES}$  sided regular polygon. As seen in Line 96,  $\text{NGEN} =$  the total number of building blocks  $= \text{NSIDES}$ .

The geometry of the  $\text{NGEN}$  building blocks is defined in the DO 100 loop from lines 97 to 121. Referring to Figure 3.1b, building block  $N$  goes from  $\phi_1 \leq \phi \leq \phi_2$ . Lines 99,100 compute  $\text{PHI1} = \phi_1$  and  $\text{PHI2} = \phi_2$ . Lines 102-109 then compute the  $(x,y)$  coordinates in meters of corners 1,2,3,4 for building block  $N$ . Line 112 indicates that the building blocks are of type 3, i.e., a sheet impedance strip from point 1 to 2, plus a quadrilateral material cylinder in the region 1,2,3,4. Line 113,114 sets  $\text{IZSHTR}(N) = 1$  and  $\text{IZSHTI}(N) = 1$ , which indicates a linear taper of both the real and imaginary parts of sheet impedance. Lines 115 and 116 define  $\text{ZSHT1}(N)$  and  $\text{ZSHT2}(N)$ , the values of the sheet impedance at point 1 and point 2, respectively, as complex  $\Omega/\square$ , i.e., a perfectly conducting strip. Finally, lines 117-120 define the material parameters of the quadrilateral cylinder.

The advantage of writing a subroutine  $\text{CGEOM}$  is the ease of changing the parameters of the cylinder. For example, if we wish to change the cylinder radii, it is only necessary to change  $A$  and  $B$  in lines 62,63 and

then CGEOM will automatically create the new geometry. By contrast, if the cylinder geometry were specified by INF.DAT, an entirely new input file would need to be created. It is hoped that the user can see that by changing a few lines, the above CGEOM could be modified to describe a coated elliptic, ogival, or rectangular cylinder.



# Chapter 4

## Example Runs

This section will present five example runs which illustrate the use of GCYL to compute the echo width of various cylinders. All data runs were made on the Ohio State University ElectroScience Laboratory VAX 8550 computer, using the GCYL code as it existed in June 1990. The Vax 8550 is about five times faster than the VAX 11/780.

### 4.1 Example 1: A Perfectly Conducting Strip

Example 1 will be to compute the backscatter echo width of a 1.0 meter wide perfectly conducting strip at  $f = 300$  Mhz. An end view of the strip is shown in Figure 4.1.

The input file for Example 1 is shown in Figure 4.2. Here, we have invoked the COM command to describe the run. The PRC command is used so that a listing of the input file will be printed in the output file. The RUN command indicates that the parameters of the problem have been checked and verified by the user, and thus the electromagnetic calculation portion of GCYL is ready to be executed. If the run for Example 1 was

executed without the RUN command, then the program would divide the conducting strip into mode size, provide in the output file a summary of the geometry and all other parameters of the input file, and then stop execution. The MDG command causes the program to print out all mode information in the output file. Without the MDG command, only general building block information is provided in the output file. Four parameters are set under the ACU command. These parameters are: INTM = 16 segment self-element numerical integrations in the material MM cells (not used in this example), INT = 6 segment numerical integrations on the strip MM modes, a maximum mode material side length of SEGM =  $0.15 \lambda$  (not used), and a maximum conductor mode length of SEGC =  $.15 \lambda$ . The FMZ command defines the frequency as FMHZ = 300.0 Mhz, and the POL command shows that NPOL = 0, indicating TM polarization. The SCP command defines the parameters that specify the desired pattern. In this case, IPAT = 0 means that the pattern will be a backscatter pattern; PHID, the angle between the positive  $x$  axis and the opposite propagation direction of the incident wave for a bistatic pattern, is set to ninety (however, it is not used in this run since we are doing a backscatter pattern); and STEP = 10 means that the step size for the pattern angle is 10 degrees. Command BT1 specifies that the general cylinder geometry will be described with an ITYP(1) = 1 building block, i.e., a sheet impedance strip. The first line of data defines the  $(x,y)$  coordinates in meters of points 1 and 2, i.e., the endpoints of the strip. In the second line we set IZSHTR(1) = 1 and IZSHTI(1) = 1, indicating that both the real and imaginary parts of the sheet impedance taper from the endpoints in a linear manner. The values of sheet impedance at the endpoints are given by ZSHT1(1) =  $(0.0,0.0) \Omega/\square$  and ZSHT2(1) =  $(0.0,0.0) \Omega/\square$ , which means that the strip is a perfectly

conducting one.

The output file for Example 1 is shown in Appendix D. The first block of output summarizes the commands of the input file. The next block of output summarizes the various run control parameters. The next block of data summarizes the parameters of the NGEN building blocks. In this case there is one building block. It is shown as a Type 1 building block (a simple sheet impedance strip) from  $(x_1, y_1) = (-0.5, 0.0)$  to  $(x_2, y_2) = (0.5, 0.0)$  meters, with a linear taper of both the real and imaginary parts of the sheet impedance, and a sheet impedance of  $0.0 + j0.0 \Omega/\square$  at each endpoint (a perfectly conducting strip). For the purpose of the MM solution the strip is segmented into 7 smaller strips, corresponding to the MM modes. The next two groups of output show the detailed geometry of these seven MM strip modes. For example, mode 3 goes from point  $IA(3) = 3$  to point  $IB(3) = 4$ , is of length 0.143 meters, and has zero sheet impedance. In command ACU the maximum MM segment size was specified as  $SEGC = 0.15$  wavelengths. In this case, the wavelength is a *free space wavelength* since the problem contains no material cylinders. At  $f = 300$  Mhz the free space wavelength is 1 meter, and thus our segment size is a maximum of 0.15 meters. Note that if the number of MM modes is reduced to 6, then the segment size would be 0.167 meters, which is larger than  $SEGC$ . The final group of output shows the backscatter echo width pattern. The echo width is shown in meters and in dB over a meter. Also shown is the magnitude and phase of the far zone scattered electric field. The backscatter pattern is plotted in Figure 4.3. The CPU time for Example 1 was about 0.23 seconds.

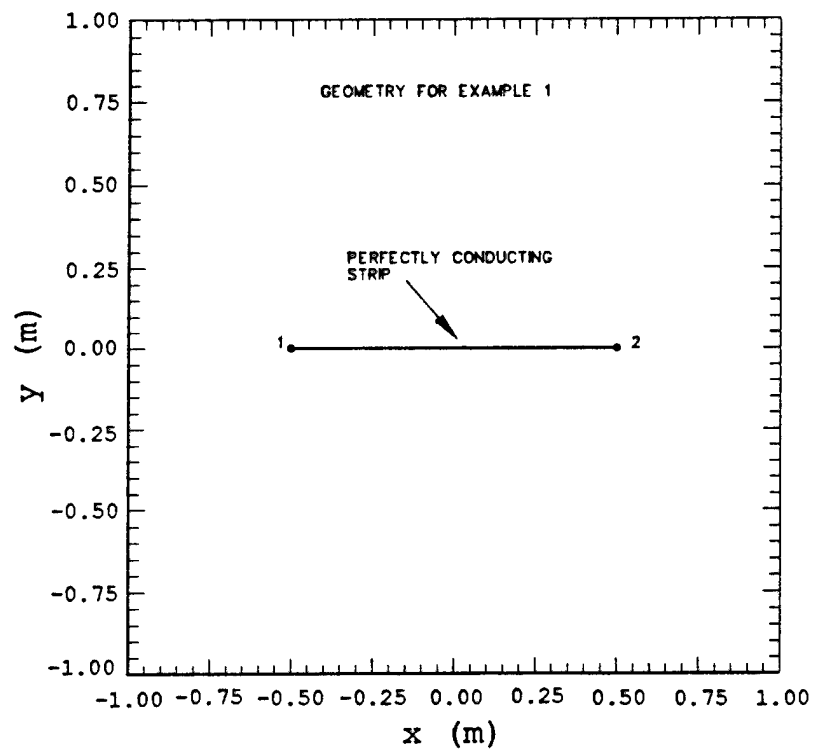


Figure 4.1: The cylinder geometry for Example 1 is a 1.0 meter wide perfectly conducting strip

```

COM
      ****EXAMPLE 1****
PRC
RUN
MDG
ACU
16 6 .15 .15
FMZ
300.
POL
0
SCP
0 90.0 10.
BT1
-.5 0.0 0.5 0.
1 1 (0.0,0.0) (0.0,0.0)
END

```

Figure 4.2: The input file for Example 1

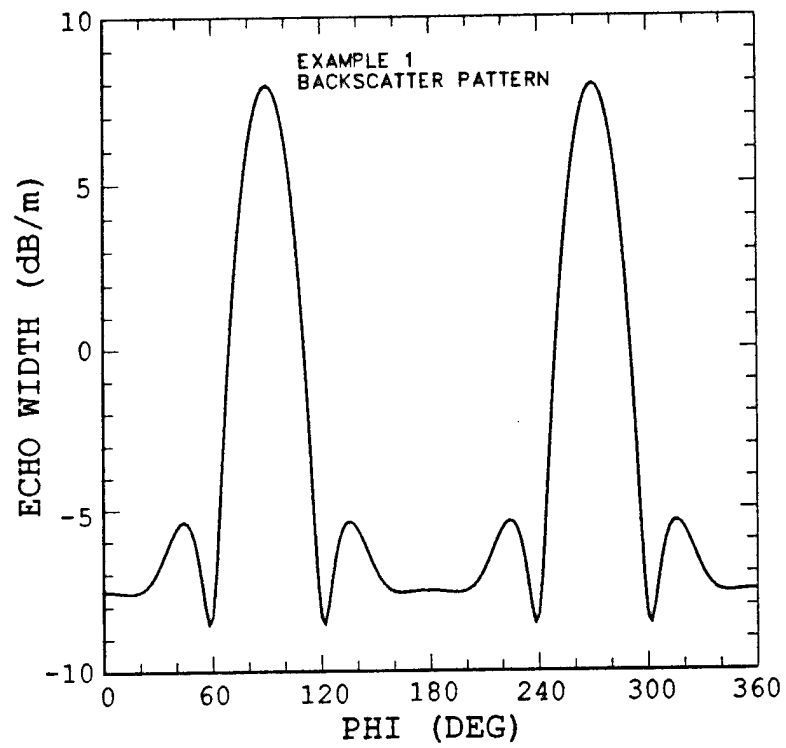


Figure 4.3: The backscatter echo width of the perfectly conducting strip in Example 1

## 4.2 Example 2: A Linear Tapered Sheet Impedance Strip

Example 2 will be to find the backscatter echo width for a tapered sheet impedance strip 1.0 meter wide at  $f = 300.0$  Mhz. The geometry of the strip is shown in Figure 4.4. Example 2 is identical to Example 1 in all respects except that Example 2 has a non-zero value of sheet impedance. Essentially, the strip is a Type 1 building block with a sheet impedance of  $Z_s = (1.0, 10.0)\Omega/\square$  at point 1 and a sheet impedance of  $Z_s = (100.0, 10.0)\Omega/\square$  at point 2.

The input file for Example 2 is shown in Figure 4.5.

The output from Example 2 is shown in Appendix E. After the commands and the run control parameters, the output shows the geometry of the one building block. It is shown as a Type 1 building block, with a linear tapered sheet impedance strip from point 1 to 2. The sheet impedance at point 1 is  $Z_s = (1.0, 10.)\Omega/\square$  and at point 2 it is  $Z_s = (100.0, 10.)\Omega/\square$ . It is indicated that the perfectly conducting strip is segmented into 7 strip modes. The detailed mode coordinates are shown next. The final output is the backscatter echo width pattern. The backscatter pattern is plotted in Figure 4.6.

The CPU time for this run was .44 seconds.

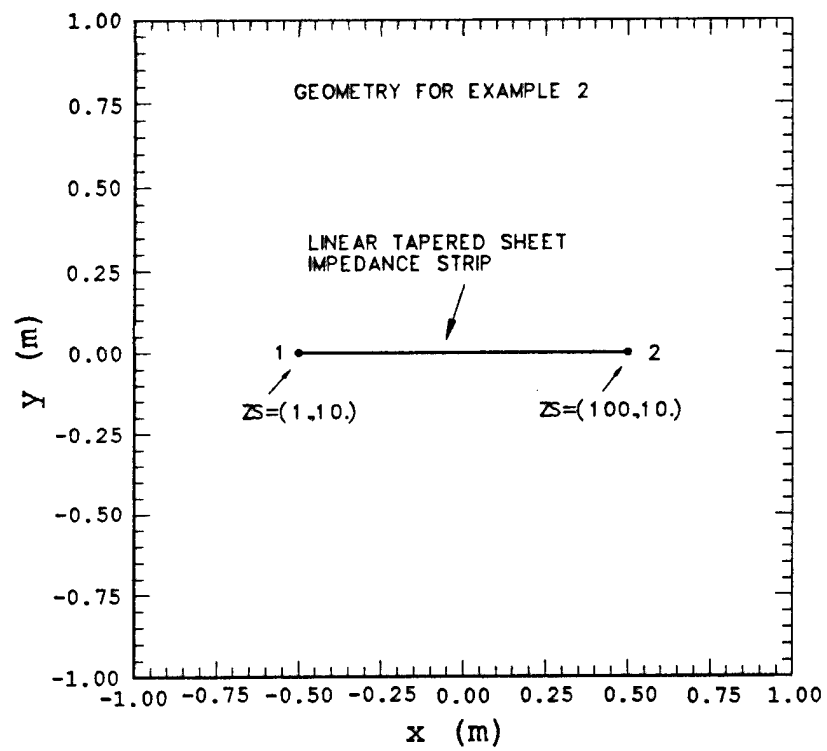


Figure 4.4: The geometry of the sheet impedance strip of Example 2



```
COM
      ****EXAMPLE 2****
PRC
RUN
MDG
ACU
16 6 .15 .15
FMZ
300.
WRI
0 0
POL
1
SCP
0 90.0 10.
BT1
-.5 0.0 0.5 0.
1 1 (1.0,10.) (100.0,10.0)
END
```

Figure 4.5: The input file for Example 2

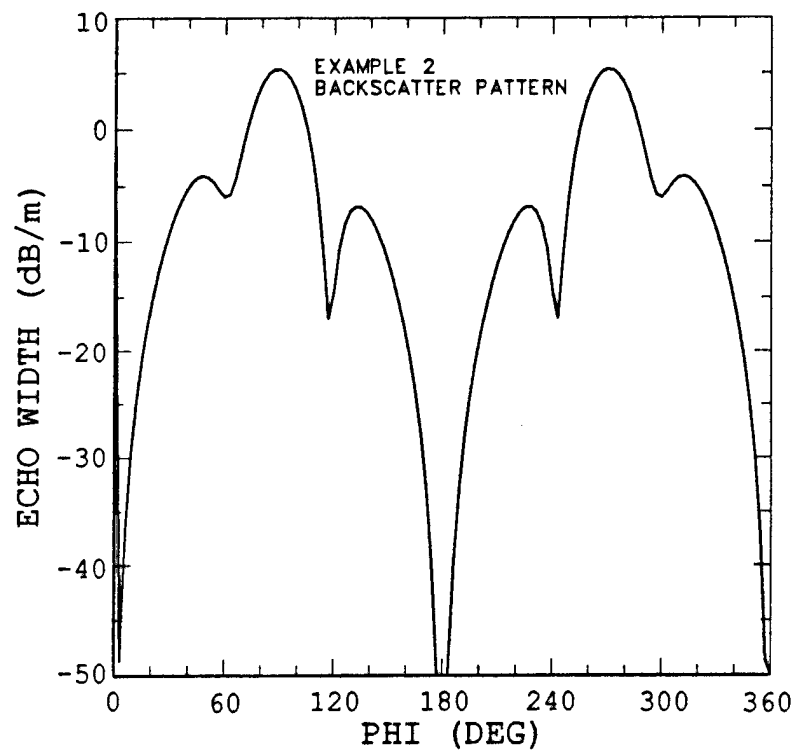


Figure 4.6: The backscatter echo width of the sheet impedance strip in Example 2

### 4.3 Example 3: A Material Coated Perfectly Conducting Strip

Example 3 will be to find the bistatic echo width for a 0.25 meter perfectly conducting strip coated with a 0.05 meter thick material coating on its surface at 300. Mhz. The permittivity and permeability of the coating are:

$$\epsilon_r = 1.5 \quad \tan \delta_e = 0.1$$

$$\mu_r = 2.0 \quad \tan \delta_m = 0.0.$$

The geometry of the coated strip is shown in Figure 4.7. Essentially, it is a Type 3 building block with a  $Z_s = 0 \ \Omega/\square$  sheet impedance from point 1 to point 2. The dashed lines in Figure 4.7 show the segmentation of the rectangular cross section material cylinder into 3 smaller rectangular cells for the purposes of the MM solution. The size of these cells should not exceed  $SEGM = 0.15$  wavelength in the material coating.

In general GCYL will segment a quadrilateral material cylinder into a number of smaller quadrilateral cells, corresponding to the MM expansion modes in the material cylinder [1]. Figure 4.8 shows a typical quadrilateral cell, defined by the  $(x,y)$  coordinates of its four corners. Side 1 of the quadrilateral cell goes from point 1 to point 2, side 2 goes from point 2 to point 3, etc. As described below, each quadrilateral cell in general corresponds to three MM expansion modes.

If the material has a permittivity different from free space, then in the TM case each cell contains an expansion mode consisting of a uniform cylinder of  $\hat{z}$  polarized electric current, shown as  $J_z$  in Figure 4.8. If the material has a permeability different from free space, then each cell contains

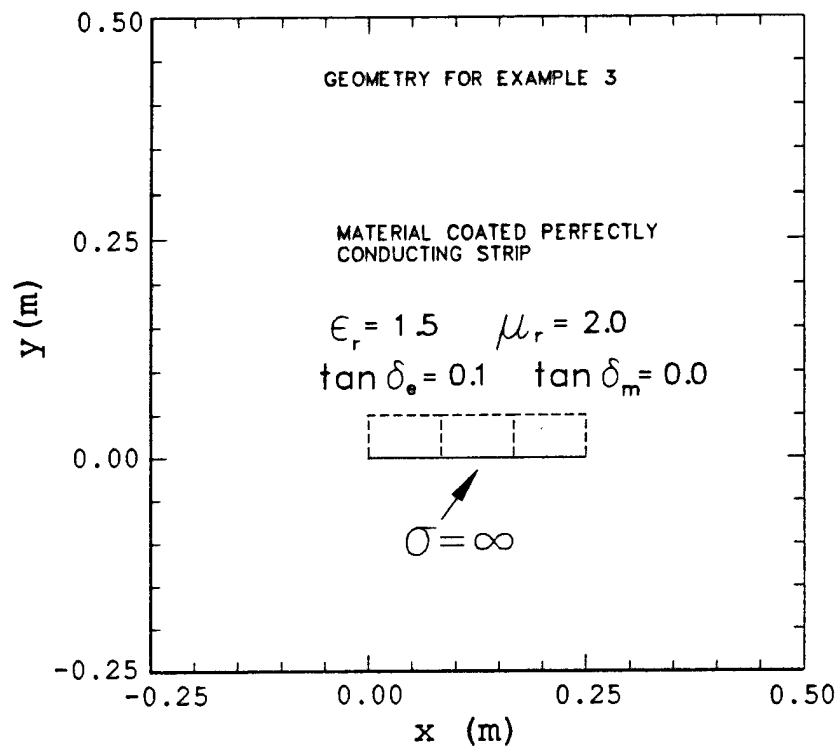


Figure 4.7: The cylinder geometry for Example 3 is a 0.25 meter wide perfectly conducting strip with a 0.05 meter thick material coating

two uniform expansion modes consisting of transverse polarized magnetic currents. One of the transverse polarized magnetic currents, denoted  $M_{13}$  in Figure 4.8, is polarized in the direction from the center of side 1 to the center of side 3. The other, denoted  $M_{42}$ , is polarized in the direction from the center of side 4 to the center of side 2. The modes are numbered so that the first are the strip modes on the conducting or sheet impedance surfaces, the next are the  $J_z$  modes in the dielectric, the next are the  $M_{13}$  modes in the ferrite, and the last are the  $M_{42}$  modes in the ferrite. In the TE case, each MM material cell which has a permittivity different from free space will have two expansion modes of electric current given by  $J_{13}$  and  $J_{42}$ , where the polarization convention is the same as for the  $M_{13}$  and  $M_{42}$  currents in the TM case. If the permeability of the material in the TE case is different from free space, then there will be a  $\hat{z}$  polarized magnetic current expansion mode given by  $M_z$ .

The input file for Example 3 is shown in Figure 4.9. The COM command describes the input file. The PRC command prints the contents of the input file in the output file. The RUN command indicates that the geometry is correct and that electromagnetic calculations are ready to be performed. The MDG command causes mode information to be printed in the output file. The ACU command specifies the accuracy parameters for the run. In this case, INTM=16 means that for self-impedance material elements, a 16 by 16 integration grid will be employed; INT=6 means that 6 integration points are used for the self-elements of conducting modes, SEGM=.15 sets the maximum length of a side of a material mode at .15 material wavelengths; and SEGC=.15 sets the maximum length of a conductor mode at .15 free space wavelengths. In the present example, SEGC is ignored since the conductor part is in contact with the material part.

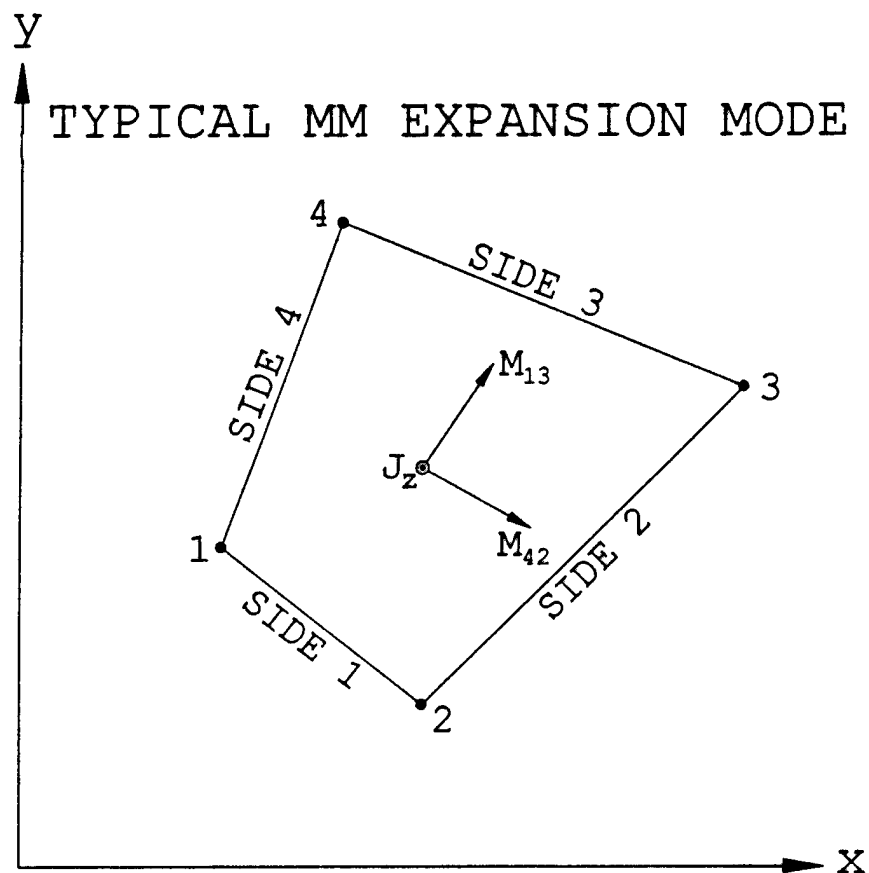


Figure 4.8: In general each quadrilateral material cell contains  $J_z$ ,  $M_{13}$ , and  $M_{42}$  MM expansion modes.

SEGC is only used if the conductor is not in edge contact with a material. The FMZ command shows that the frequency in megahertz is FMHZ=300. The WRI command indicates that IZWR=1 and ICWR=1, meaning the impedance matrix, voltage vector, and current vector are to be printed in the output file. The POL command sets NPOL=0, which indicates TM polarization. The SCP command sets IPAT=1, which means a bistatic pattern is to be calculated, PHID=90.0, which sets the angle of the incident wave at 90.0 degrees, and STEP=10.0, which indicates that a pattern calculation is to be made every 10.0 degrees. The BT3 command means that we have a type 3 building block; i.e., a coated sheet impedance strip. Points 1 and 2 are given on the first data line, while points 3 and 4 are given on the second data line. The permittivity and permeability are given on the next line, and the final data line indicates a perfectly conducting strip. The END command indicates the end of the data file.

The output from Example 3 is shown in Appendix F. After the listing of the input file, run control parameters, and the frequency, the output shows the geometry of the one building block. It is shown as a Type 3 building block, with a perfectly conducting strip from point 1 to 2. The permittivity and permeability of the quadrilateral cylinder 1,2,3,4 are printed. It is indicated that the perfectly conducting strip is segmented into 3 strip modes, and the material cylinder into 3 cells. This will result in 3 conductor modes, 3 dielectric modes, and 6 ferrite modes. The detailed mode coordinates are shown next. The next output is the nine blocks of the MM impedance matrix [1]. Here M and N are row and column indices of the [Z] matrix, while ML and NL are local row and column indices for the particular block of the [Z] matrix. The next two outputs are the voltage and current vector for a wave incident from  $\phi_i = \text{PHID} = 90^\circ$ . The first 3 elements in these

```

COM
      ****EXAMPLE 3****
PRC
RUN
MDG
ACU
16 6 .15 .15
FMZ
300.
WRI
1 1
POL
0
SCP
1 90.0 10.
BT3
0.0 0.0 0.25 0.
.25 .05 0. .05
1.5 .01 2. 0.0
1 1 (0.0,0.0) (0.0,0.0)
END

```

Figure 4.9: The input file for Example 3



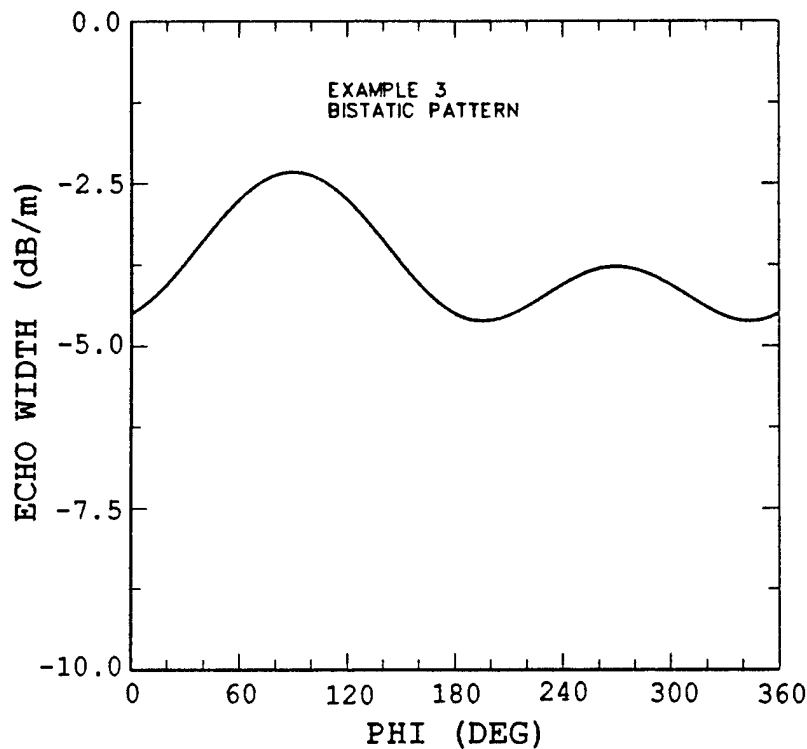


Figure 4.10: The bistatic echo width of the coated perfectly conducting strip in Example 3

vectors refer to the conductor modes, the next 3 to the  $J_z$  modes in the material cylinder, the next 3 to the  $M_{13}$  modes in the material cylinder, and the last 3 to the  $M_{42}$  modes in the material cylinder. The final output is the bistatic echo width pattern. Figure 4.10 shows a plot of the bistatic echo width. The CPU time for this run was about 2. seconds.

#### 4.4 Example 4: A Corner Reflector

Example 4 will be to compute the bistatic echo width of a corner reflector for TE polarization at  $f = 300$  Mhz. The corner reflector geometry is shown

in Figure 4.11. The corner reflector consists of two perfectly conducting strips joined at a right angle and coated by a material with a permittivity of

$$\epsilon_r = 3.0 \qquad \tan \delta_e = 0.1$$

and a permeability of

$$\mu_r = 1.0 \qquad \tan \delta_m = 0.0.$$

The input file for Example 4 is shown in Figure 4.12. The COM command describes the input file. The PRC command prints the contents of the input file in the output file. The RUN command indicates that the geometry is correct and that electromagnetic calculations are ready to be performed. The MDG command causes mode information to be printed in the output file. The ACU command specifies the accuracy parameters for the run. In this case, INTM=16 means that for self-impedance material elements, a 16 by 16 integration grid will be employed; INT=6 means that 6 integration points are used for the self-elements of conducting modes, SEGM=.15 sets the maximum length of a side of a material mode at .15 material wavelengths; and SEGC=.15 sets the maximum length of a conductor mode at .15 free space wavelengths. In the present example, SEGC is ignored since the conductor part is in edge contact with the material part. The FMZ command sets the frequency at FMZ = 300.0 Mhz, and the parameters under the WRI command indicate that the voltage vector and current vector are to be printed out (ICWR=1), but not the impedance matrix (IZWR=0). The POL command is used to indicate TE polarization (NPOL=1). The parameters under the SCP command show that a bistatic pattern is desired (IPAT=1), with a pattern step of 5. degrees (STEP=5.), and the incidence angle is 45. degrees (PHID=45.). The BT3 command

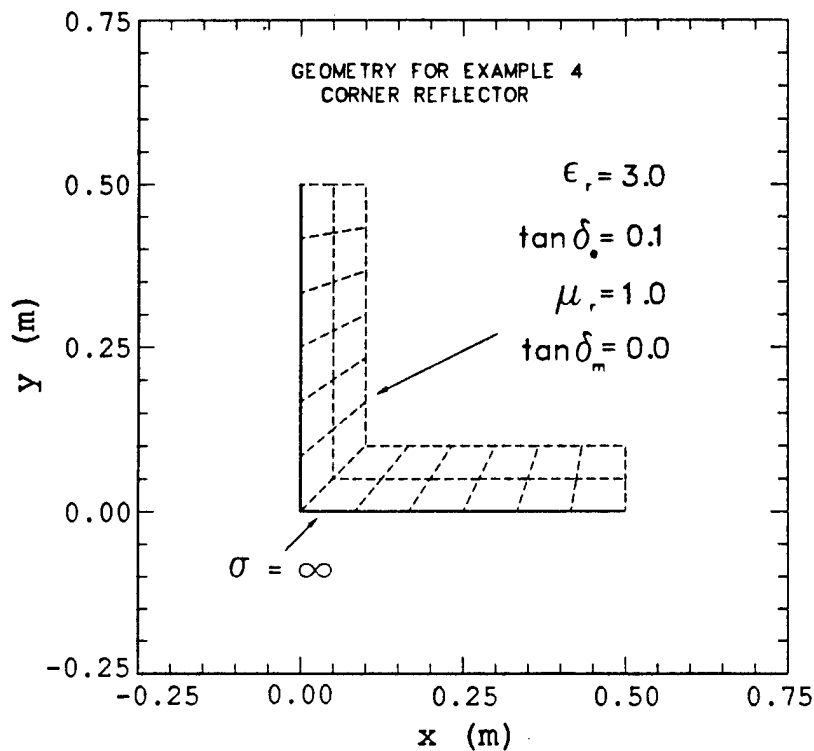


Figure 4.11: The geometry of the material coated corner reflector of Example 4

means that we have a type 3 building block; i.e., a coated sheet impedance strip. Points 1 and 2 are given on the first data line, while points 3 and 4 are given on the second data line. The permittivity and permeability are given on the next line, and the final data line indicates a perfectly conducting strip. Using two BT3 building blocks, the corner reflector of Figure 4.11 is constructed. The END command indicates the end of the data file.

The output for Example 4 is shown in Appendix G. After a summary of the input file and the run control parameters, there is a listing of the 2 building blocks. It is seen that they are type 3 building blocks (i.e.

```

COM
      ****EXAMPLE 4****
RUN
PRC
MDG
ACU
16 6 .15 .15
FMZ
300.
WRI
0 1
POL
1
SCP
1 45.0 5.
BT3
0.0 0.0 0.0 0.5
.1 .5 .1 .1
3. .1 1.0001 0.
1 1 (0.0,0.0) (0.0,0.0)
BT3
0.0 0.0 0.5 0.0
.5 .1 .1 .1
3. .1 1.00001 0.
1 1 (0.0,0.0) (0.0,0.0)
END

```

Figure 4.12: The input file for Example 4

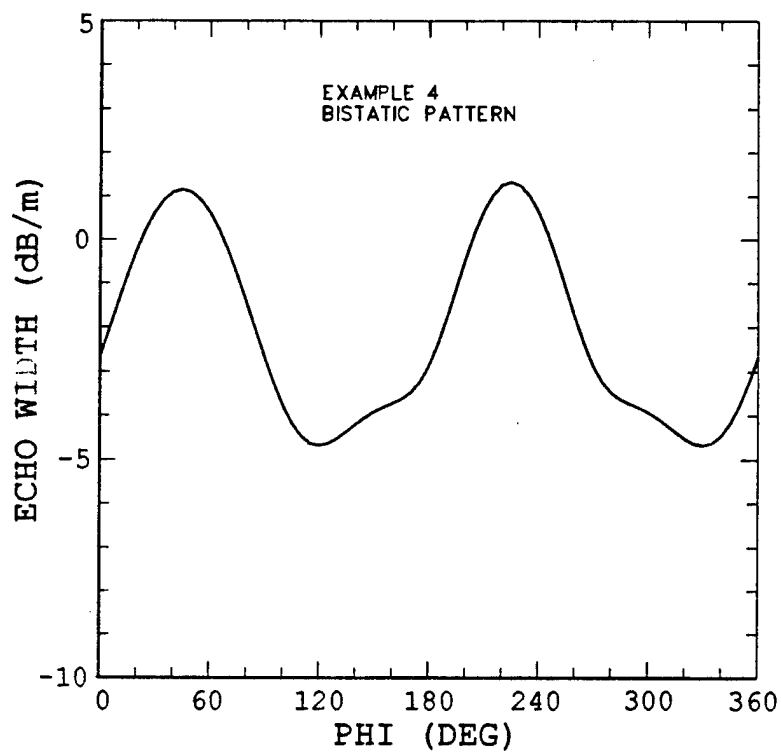


Figure 4.13: The bistatic echo width of the coated corner reflector of Example 4

coated strips), with the conducting strips extending from point 1 to point 2, whereas the dielectric material is confined by the quadrilateral regions defined by points 1,2,3, and 4. Since the building blocks are the same in physical extent and composition, they are divided in the same manner: 6 conductor segments and 12 material cells. Next is a summary of mode information. Note that although there are a total of 12 conducting segments, there are only 11 conducting modes. This is because the sinusoidal expansion functions of the TE solution extend over two segments. As a result, this particular geometry dictates the need for only 11 conductor expansion modes. There are in general 3 modes per material cell in a dielectric and ferrite material. In the TE case there are 2 dielectric modes per cell ( $J_{13}$  and  $J_{42}$ ), and 1 ferrite mode per cell ( $M_z$ ). As a consequence, from 24 material cells we have 48 dielectric modes and 24 ferrite modes. In the present state of the GCYL code, TE material examples always include ferrite modes in the solution, whether or not the permeability is the free space permeability or some other one. The next output is a summary of the mode information. Following the mode information is a listing of the voltage vector and the current vector. Next is the output for the bistatic pattern. The bistatic pattern is plotted in Figure 4.13. The run time was about 97 seconds.

## 4.5 Example 5: A Material Coated Perfectly Conducting Cylinder

Example 5 will be to compute the bistatic echo width of a coated perfectly conducting circular cylinder at  $f = 300$  Mhz. The cylinder geometry is shown in Figure 4.14. The radius of the perfectly conducting cylinder is 0.15 meters, while the outer radius of the material coating is 0.25 meters.

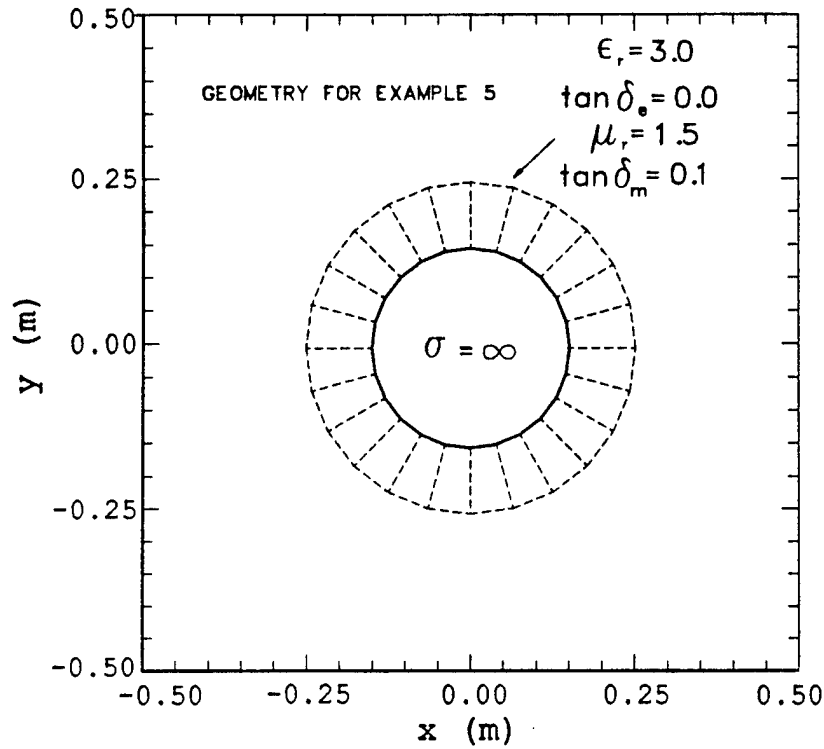


Figure 4.14: The geometry of Example 5 consists of a material coated perfectly circular cylinder.

The parameters of the material coating are:

$$\epsilon_r = 3.0 \quad \tan \delta_e = 0.0$$

$$\mu_r = 1.5 \quad \tan \delta_m = 0.1.$$

This coated cylinder geometry is defined by the subroutine CGEOM shown in Appendix A, and which is described in Section 3.18.2.

The input file for Example 5 is shown in Figure 4.15. This input file has basically the same form as Examples 1-4, with the one major difference being the addition of the SUB command, which implies that building block

information is to be input via the subroutine CGEOM in Appendix A. Notice that there are no building block commands in the input file. From the input file, we see that the run will be made at  $f = 300.0$  Mhz, the polarization is TE, and that the pattern will be bistatic, with the angle of incidence being 0.0 degrees, and a pattern step of 5. degrees.

The output file for Example 5 is shown in Appendix H. Note that in the listing of commands and inputs the SUB command has been invoked, indicating that the building block information for the run has been generated from subroutine CGEOM as listed in Appendix A. The next output is the summary of run control parameters. Following that is the building block information generated by subroutine CGEOM. It is seen that the 24 building blocks approximate a dielectric/ferrite coating of a circular conducting cylinder. The outer radius of the conducting circular cylinder is .15 meters, while the outer radius of the coating is .25 meters. The parameters of the material coating are:

$$\epsilon_r = 3.0 \qquad \tan \delta_e = 0.0$$

$$\mu_r = 1.5 \qquad \tan \delta_m = 0.1.$$

Next, a summary of modes is given, including detailed mode geometry information. Finally the bistatic pattern is output. This pattern is shown in Figure 4.16, where it is compared to an exact eigenfunction solution [7]. The CPU time for Example 5 was 316 seconds.



```
COM
      ****EXAMPLE 5****
RUN
PRC
MDG
SUB
ACU
16 6 .15 .15
FMZ
300.
WRI
0 0
POL
1
SCP
1 0.0 5.
END
```

Figure 4.15: The input file for Example 5.

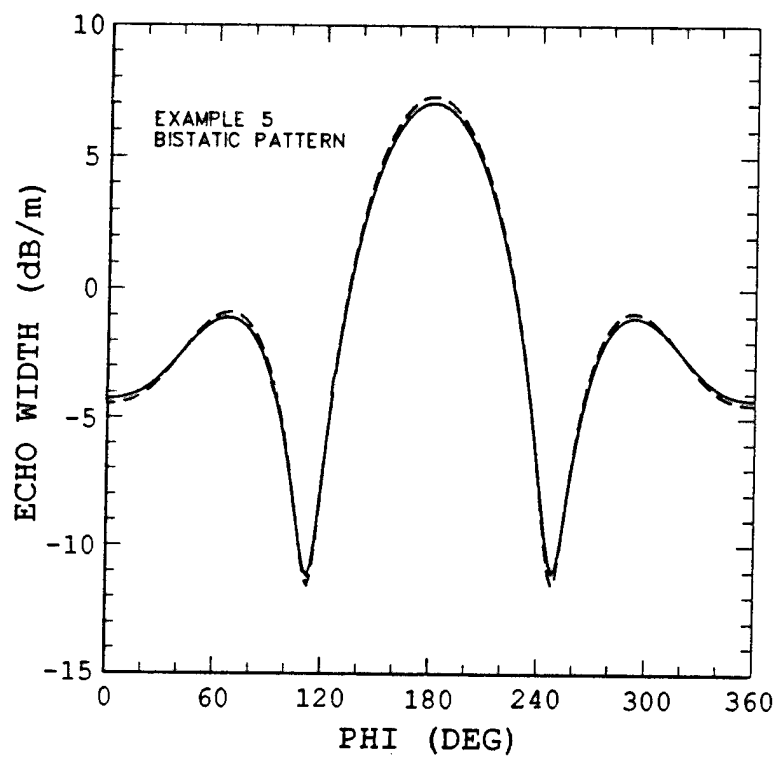


Figure 4.16: The bistatic scattering pattern of Example 5 is compared to an exact eigenfunction solution.

## Chapter 5

# Array Dimensions and Output Files

### 5.1 Array Dimensions

GCYL contains many arrays which hold the general cylinder geometry, as well as matrices and vectors used in the MM solution. The required size of these arrays is dependent upon the number of modes in the MM solution. All arrays in GCYL are dimensioned according to the two dimension indicators, IDMM and IDM, specified by PARAMETER statements at the top of the main program. A user may need to increase these dimension indicators in order to run a larger problem, or he may need to decrease them in order to "fit" GCYL on a machine with limited core storage.

The dimension indicators are defined as follows:

**IDMM** = maximum number of MM strip segments + maximum number of material cells (typically set to 550).

**IDM** = maximum number of MM modes

= maximum number of MM strip segment modes plus three times the maximum number of material cells (typically set to 1300).

Most of the core storage is in the complex array  $Z(IDM, IDM)$  which holds the MM impedance matrix (see Equation (1.1)).

## 5.2 Data for Geometry Plots

The output files shown in Appendices D-H provide block as well as modal descriptions of the input geometry. However, one is often interested in obtaining a visual plot of both building block data and modal data to verify that the correct geometry has been input. To aid the user in obtaining a visual image of the geometry, GCYL outputs a disk file, referred to as GPLOT, on logical unit 9. In addition, a listing of a fortran code called GEOMP is provided in Appendix B. GEOMP reads the data from file GPLOT and calls a GKS plotting subroutine named PLOTTER as well as subroutine IPOINT to generate a plot of the problem geometry. GEOMP generates a plot of either the building block geometry or the mode geometry or both.

GPLOT contains both building block geometry data and mode geometry data. It can be read with free format. In the building block part of GPLOT, the first line of GPLOT lists:

NGEN

NGEN = total number of general building blocks

The remaining lines of the building block part of GPLOT provide a tabular listing of the building block information. For a complete discussion of the different types of general building blocks available to the user, refer to Chapter 2 of this manual. Each building block line begins with the building block type:

ITYP

**ITYP** = 1 means a sheet impedance strip

2 means a material quadrilateral region

3 means a strip coated by a material quadrilateral region

4 means a strip coated on each side by material quadrilateral regions

5 means a quadrilateral region with strips adjacent to none, some, or all sides.

Only geometrical information is listed for a given building block type. This is because once we know what type of building block we have (BT1-BT5), only geometrical information about the block is needed to generate a plot of that block. The description for the output of each type of block follows. For a type 1 block:

X1 Y1 X2 Y2

**X1,Y1** = ( $x,y$ ) coordinates of point 1 of the impedance strip (meters).

**X2,Y2** = ( $x,y$ ) coordinates of point 2 of the sheet impedance strip (meters).

For a type 2 block:

$X_1 Y_1 X_2 Y_2$

$X_3 Y_3 X_4 Y_4$

$X_N, Y_N = (x, y)$  coordinates of point N of the quadrilateral region (meters).

For a type 3 block:

$X_1 Y_1 X_2 Y_2$

$X_3 Y_3 X_4 Y_4$

$X_N, Y_N = (x, y)$  coordinates of point N of the quadrilateral region 1,2,3,4 (meters). (note: in a type 3 block the strip lies on side 1,2 of the quadrilateral)

For a type 4 block:

$X_1 Y_1 X_2 Y_2$

$X_3 Y_3 X_4 Y_4$

$X_{3P} Y_{3P} X_{4P} Y_{4P}$

$X_N, Y_N = (x, y)$  coordinates of point N of the quadrilateral region I (meters).

$X_{NP}, Y_{NP} = (x, y)$  coordinates of point N = 3' or 4' of quadrilateral region II.

For a type 5 block:

X1 Y1 X2 Y2 X3 Y3 X4 Y4

IZ12 IZ23 IZ34 IZ41

**XN,YN** =  $(x,y)$  coordinates of point N of the quadrilateral region (meters).

**IZ12** = 0 if there is no sheet impedance strip on side12 of quadrilateral region 1,2,3,4.

= 1 if there is a sheet impedance strip on side12 of quadrilateral region 1,2,3,4.

**IZ23** = 0 if there is no sheet impedance strip on side23 of quadrilateral region 1,2,3,4.

= 1 if there is a sheet impedance strip on side23 of quadrilateral region 1,2,3,4.

**IZ34** = 0 if there is no sheet impedance strip on side34 of quadrilateral region 1,2,3,4.

= 1 if there is a sheet impedance strip on side34 of quadrilateral region 1,2,3,4.

**IZ41** = 0 if there is no sheet impedance strip on side41 of quadrilateral region 1,2,3,4.

= 1 if there is a sheet impedance strip on side41 of quadrilateral region 1,2,3,4.

The remaining lines of GPLOT provide mode geometry information The first line of mode information is:

LMD NM

**LMD** = total number of material quadrilateral cells.

**NM** = total number of strip segment modes.

The next NM line are a tabular listing of the strip segment modes. Each line defines:

X1 Y1 X2 Y2

**X1,Y1** =  $(x,y)$  coordinates of point 1 of the impedance strip (meters).

**X2,Y2** =  $(x,y)$  coordinates of point 2 of the sheet impedance strip (meters).

The next 4\*LMD lines define:

X1 Y1

X2 Y2

X3 Y3

X4 Y4

**XN,YN** =  $(x,y)$  coordinates of point N of the quadrilateral region (meters).



### 5.3 Data for Pattern Plots

The output files shown in Appendices D-H provide tabular listings of the echo width patterns. However, often one desires a plot of these patterns. To aid a user who wishes to obtain a pattern plot, GCYL outputs a disk file on logical unit 7. This file will be referred to as PLOT.

PLOT contains ISTEP + 1 lines of output. It can be read with free format. The first line of PLOT lists:

**FMHZ** = frequency in Mhz.

**IPAT** = indicator for type of pattern

= 0 implies a backscatter pattern = 1 implies a bistatic scatter pattern.

**ISTEP** = the number of pattern points going from  $0 \leq \phi_s \leq 360^\circ$ .

**PHID** = the angle of the incident wave in degrees for bistatic patterns.

**NTOTT** = the total number of MM modes.

The remaining NSTEP lines of PLOT provide a tabular listing of the pattern. Each line defines:

**PHISD** = angle of the scattered wave in degrees.

**WDBM** = echo width in dB over a meter.

**PESCTD** = phase of the far zone scattered electric field in degrees.

# Chapter 6

## Summary

This report serves as a user's manual for a computer code (GCYL) which can compute the TM/TE scattering from a general cylinder. A general cylinder is composed of:

1. perfectly conducting cylinders of arbitrary cross section
2. lossy and inhomogeneous dielectric and/or ferrite material cylinders of arbitrary cross section
3. electrically thin dielectric strips modeled by a sheet impedance (including tapered sheet impedances).

The general cylinder geometry is constructed from a number of building blocks which are perfectly conducting or sheet impedance strips (constant or tapered) and quadrilateral cross section dielectric/ferrite cylinders. In this way, a cylinder of essentially arbitrary cross section, and with essentially arbitrary lossy and inhomogeneous material composition, can be constructed. This manual describes the basic use of GCYL, including code inputs and outputs.

# Bibliography

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- [5] J.H. Richmond, "An Integral-Equation Solution for TE Scattering from Conducting Cylinders", Ohio State University, Department of Electrical Engineering, Technical Report 2902-7, October, 1972.
- [6] E.H. Newman and J.L. Blanchard, "TM Scattering by an Impedance Sheet Extension of a Parabolic Cylinder", IEEE Trans. on Antennas and Propagation, vol. AP-36, April 1988, pp. 527-534.
- [7] Eigenfunction solution for the material coated perfectly conducting circular cylinder supplied by Prof. J.H. Richmond of the Ohio State University ElectroScience Lab.

# Appendix A

## Subroutine CGEOM for a Coated Circular Cylinder

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```
0001
0002      SUBROUTINE CGEOM(FMHZ,SEGM,SEGC,NGEN,ITYP,X1,Y1,X2,Y2,X3,Y3,
0003      2 X4,Y4,X3P,Y3P,X4P,Y4P,IZSHTR,IZSHTI,ZSHT1,ZSHT2,ZSHT3,ZSHT4,
0004      3 ER,TDE,UR,TDM,ERP,TDEP,URP,TDMP,IDIE,IFER)
0005      C
0006      C      CGEOM DEFINES GENERAL BUILDING BLOCKS FOR A MATERIAL
0007      C      COATED PERFECTLY CONDUCTING CIRCULAR CYLINDER COATED
0008      C      WITH FERRITE/DIELECTRIC MATERIAL.
0009      C
0010      C INPUTS:
0011      C
0012      C      FMHZ = FREQUENCY IN MEGAHERTZ
0013      C      SEGM = MAX. LENGTH OF A CELL OR SEGMENT LENGTH(IN MATERIAL
0014      C                                     SPACE
0015      C      SEGC = MAX. LENGTH OF A CONDUCTOR SEGMENT (IN FREE SPACE
0016      C      WV'S)
0017      C      OUTPUTS:
0018      C
0019      C      NGEN=NO. OF BUILDING BLOCKS
```

```

0020 C      ITYP(I)=1 IMPLIES A SHEET IMPEDANCE STRIP
0021 C      =2 IMPLIES A MATERIAL QUAD.
0022 C      =3 IMPLIES A SHEET IMPEDANCE WITH MATERIAL COAT
ON
0023 C      ONE SIDE
0024 C      =4 IMPLIES A SHEET IMPEDANCE WITH MATERIAL COATING
0025 C      ON BOTH SIDES
0026 C      =5 IMPLIES A MATERIAL QUAD. COATED WITH A SHEET
0027 C      IMPEDANCE ON BOTH SIDES
0028 C      ARRAYS:
0029 C      X1,X2,X3,X4 = X COORDINATES OF PTS. 1,2,3,4 OF QUAD.
REGION
0030 C Y1,Y2,Y3,Y4 = Y COORDINATES OF PTS. 1,2,3,4 ' ' '
0031 C      X3P,X4P = X COORDINATES OF PTS. 3,4 OF 2nd COAT
0032 C      Y3P,Y4P = Y COORDINATES OF PTS. 3,4 OF 2nd COAT
0033 C      IZSHTR(NG)=1 IMPLIES A LINEAR TAPERED REAL PART SHEET
IMPEDANCE
0034 C      =2 IMPLIES AN EXPONENTIALLY REAL
0035 C      PART TAPERED SHEET IMPEDANCE
0036 C      IZSHTI(NG)=1 IMPLIES A LINEAR TAPERED
0037 C      IMAGINARY PART OF THE SHEET IMPEDANCE
0038 C      =2 IMPLIES AN EXPONENTIALLY TAPERED
0039 C      IMAGINARY PART OF THE SHEET IMPEDANCE
0040 C      ZSHTN(I) =FOUR ARRAYS HOLDING THE SHEET IMPEDANCE AT
THE Nth pt.
0041 C
0042 C
0043 C      ER(I) = RELATIVE PERMITTIVITY OF THE Ith BLOCK
0044 C      TDE(I) = ELECTRIC LOSS TANGENT OF THE Ith ' '
0045 C      UR(I) = RELATIVE PERMEABILITY ' ' ' '
0046 C      TDM(I) = MAGNETIC LOSS TANGENT ' ' ' '
0047 C      ERP(I) = RELATIVE PERMITTIVITY OF THE 2nd COAT OF THE
Ith BLOCK
0048 C      TDEP(I)= ELECTRIC LOSS TANGENT ' ' ' ' '
' '
0049 C      URP(I) = RELATIVE PERMEABILITY ' ' ' ' '
' '
0050 C      TDMP(I)= MAGNETIC LOSS TANGENT ' ' ' ' '
' '
0051 C      IDIE = INDICATOR FOR DIELECTRIC
0052 C      IFER = INDICATOR FOR FERRITE
0053 C
0054 C      DIMENSION X1(1),Y1(1),X2(1),Y2(1),X3(1),Y3(1),X4(1),Y4(1),
0055 2 X3P(1),Y3P(1),X4P(1),Y4P(1),IZSHTR(1),IZSHTI(1)

```

0056            DIMENSION ITYP(1),ER(1),TDE(1),UR(1),TDM(1),  
0057            2   ERP(1),TDEP(1),URP(1),TDMP(1)

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0058            COMPLEX ZSHT1(1),ZSHT2(1),ZSHT3(1),ZSHT4(1)  
0059        C        DEFINE PI  
0060            DATA PI /3.141593/  
0061        C        SPECIFY A = INNER RADIUS AND B = OUTER RADIUS  
0062            AA=.25  
0063            BB=0.15  
0064        C        SPECIFY THE MATERIAL PARAMETERS OF THE COATING  
0065            ERC=3.000  
0066            TDEC=0.  
0067            IDIE=1  
0068            URC=1.5  
0069            TDMC=0.1  
0070            IFER=1  
0071        C        COMPUTE THE WAVELENGTH IN AIR AND IN THE COATING  
0072            WVO=300.0/FMHZ  
0073            WVC=WVO/SQRT(ERC\*URC)  
0074        C        COMPUTE THE MAXIMUM SEGMENT SIZE FOR THE MM MODES  
0075            SMAX=SEGM\*WVC  
0076        C        IF THIS WAS A PURELY CONDUCTING CYLINDER, THEN ONE  
0077        C        WOULD USE SMAX=SEGC\*WVC.  
0078        C        COMPUTE THE ANGULAR DPHI OF EACH SIDE OF THE POLYGON  
0079            DPHI=2.0\*ASIN(SMAX/(2.0\*BB))  
0080        C        COMPUTE THE NUMBER OF SIDES IN THE POLYGON, INSURING  
0081        C        THAT IT IS AN EVEN NUMBER. ALSO RESET DPHI  
0082            NSIDES=IFIX(0.99+(2.0\*PI/DPHI))  
0083            NSIDES=2\*((NSIDES+1)/2)  
0084            IF(NSIDES.LT.4)NSIDES=4  
0085            DPHI=2.0\*PI/NSIDES  
0086        C  
0087        C        ADJUST THE RADII FOR EQUAL AREA  
0088        C  
0089            FAC=SQRT(PI/(NSIDES\*COS(0.5\*DPHI)\*SIN(0.5\*DPHI)))  
0090            A=AA\*FAC  
0091            B=BB\*FAC  
0092            TYPE\*, 'AA,BB = ',AA,BB  
0093            TYPE\*, 'A,B = ',A,B  
0094        C        DEFINE THE NGEN = NSIDES GENERAL BUILDING BLOCKS

```

0095      C      REPRESENTING THE COATED PERFECTLY CONDUCTING CYLINDER.
0096          NGEN=NSIDES
0097          D0100N=1,NGEN
0098      C      GENERAL BUILDING BLOCK N GOES FROM PHI1 TO PHI2
0099          PHI1=(N-1)*DPHI
0100          PHI2=PHI1+DPHI
0101      C      COMPUTE THE X,Y COORDINATES OF POINTS 1,2,3,4.
0102          X1(N)=A*COS(PHI1)
0103          Y1(N)=A*SIN(PHI1)
0104          X2(N)=A*COS(PHI2)
0105          Y2(N)=A*SIN(PHI2)
0106          X3(N)=B*COS(PHI2)
0107          Y3(N)=B*SIN(PHI2)
0108          X4(N)=B*COS(PHI1)
0109          Y4(N)=B*SIN(PHI1)
0110      C      DEFINE THE BLOCK TYPE, SHEET IMPEDANCE, AND
0111      C      MATERIAL PARAMETERS OF THE GENERAL BUILDING BLOCKS.
0112          ITYP(N)=3
0113          IZSHTR(N)=1
0114          IZSHTI(N)=1

```

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```

0115          ZSHT1(N)=(0.0,0.0)
0116          ZSHT2(N)=(0.0,0.0)
0117          ER(N)=ERC
0118          TDE(N)=TDEC
0119          UR(N)=URC
0120          TDM(N)=TDMC
0121      100      CONTINUE
0122          RETURN
0123          END

```

## Appendix B

### Subroutine GEOMP for Generating Block and Mode Geometry Plots

```
0001      C
0002      C      PROGRAM GEOMP ACCEPTS BLOCK COORDINATE AND
0003      C      MODE COORDINATE INFORMATION
0004      C      AND PRODUCES A PLOT OF THE GEOMETRY
0005      C
0006      C
0007      C      DECLARING VARIABLES
0008      C
0009      DIMENSION X(2),Y(2),XN1(5),YN1(5),XC(1000),YC(1000)
0010      INTEGER LMD,NM,NT,NGEN
0011      NT=0
0012      C
0013      C      IGEOM = 0 IF ONLY THE GENERAL BUILDING BLOCK GEOMETRY
IS TO BE PLOTTED
0014      C      1 IF ONLY THE MODE GEOMETRY IS TO BE PLOTTED
0015      C      2 IF BOTH PLOTS ARE TO BE PLOTTED
0016      C
0017      TYPE*, 'SELECT GEOMETRY TO BE PLOTTED: 0=BLOCK 1=MODE
2=BOTH'
0018      ACCEPT*, IGEOM
0019      C
0020      C      READ: NGEN = NUMBER OF BUILDING BLOCKS
```



```

0021      C
0022          READ(9,*)NGEN
0023
0024          DO 5 I=1,NGEN
0025      C
0026      C          READ: ITP = TYPE OF BUILDING BLOCK: 1=BT1 2=BT2 3=BT3
4=BT4 5=BT5
0027      C
0028          READ(9,*)ITP
0029      C
0030      C          READ: X1,Y1,X2,Y2 = POINT 1 AND POINT 2 OF BLOCK
0031      C
0032          READ(9,*)X(1),Y(1),X(2),Y(2)
0033      C
0034      C          PLOTTING SHEET IMPEDANCE PART FOR BT1-BT4
0035      C
0036          IF(ITP.NE.2.AND.ITP.NE.5.AND.IGEOM.NE.1)THEN
0037              NT=NT+1
0038              IF(NT.EQ.99)NT=NT+1
0039      C
0040      C          IN PLOTTER 0 INDICATES A SINGLE PLOT
0041      C
0042          IF(I.EQ.NGEN.AND.NGEN.EQ.1.AND.ITP.EQ.1)NT=0
0043          CALL PLOTTER(X,Y,2,-90,0,1,NT)
0044      ENDIF
0045
0046          IF(ITP.GT.1)THEN
0047      C
0048      C          READ: X3,Y3,X4,Y4 = POINT 3 AND POINT 4 OF BLOCK
0049      C
0050          READ(9,*)XN1(3),YN1(3),XN1(4),YN1(4)
0051          XN1(1)=X(1)
0052          YN1(1)=Y(1)
0053          XN1(2)=X(2)
0054          YN1(2)=Y(2)
0055          ENDIF
0056          IF(ITP.EQ.5)THEN
0057      C
0058      C          READ: I12,I23,I34,I41 = 0 FOR NO SHEET IMPEDANCE ON
SIDE12(23)(34)(41)
0059      C
0060      C          1 FOR A SHEET IMPEDANCE ON SIDE12(23)(34)(4
0061          READ(9,*)I12,I23,I34,I41
0062      C

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```

0063 C          PLOTTING THE SHEET IMPEDANCE PART OF A BT5 BLOCK
0064 C
0065          IF(IGEOM.NE.1)THEN
0066              IF(I12.EQ.1)THEN
0067                  NT=NT+1
0068              IF(NT.EQ.99)NT=NT+1
0069              CALL PLOTTER(X,Y,2,-90,0,1,NT)
0070              ENDIF
0071              IF(I23.EQ.1)THEN
0072                  NT=NT+1
0073                  X(1)=XN1(2)
0074                  Y(1)=YN1(2)
0075              X(2)=XN1(3)
0076                  Y(2)=YN1(3)
0077              IF(NT.EQ.99)NT=NT+1
0078              CALL PLOTTER(X,Y,2,-90,0,1,NT)
0079              ENDIF
0080              IF(I34.EQ.1)THEN
0081                  X(1)=XN1(3)
0082                  Y(1)=YN1(3)
0083              X(2)=XN1(4)
0084                  Y(2)=YN1(4)
0085                  NT=NT+1
0086              IF(NT.EQ.99)NT=NT+1
0087              CALL PLOTTER(X,Y,2,-90,0,1,NT)
0088              ENDIF
0089              IF(I41.EQ.1)THEN
0090                  NT=NT+1
0091                  X(1)=XN1(4)
0092                  Y(1)=YN1(4)
0093              X(2)=XN1(1)
0094                  Y(2)=YN1(1)
0095              IF(NT.EQ.99)NT=NT+1
0096              CALL PLOTTER(X,Y,2,-90,0,1,NT)
0097              ENDIF
0098          ENDIF
0099      ENDIF
0100 C
0101 C          PLOTTING QUADRILATERAL INFORMATION FOR BT2-BT5
0102 C
0103          IF(ITP.NE.1)THEN
0104              IF(IGEOM.NE.1)THEN
0105                  X(1)=XN1(1)
0106                  Y(1)=YN1(1)

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0107      X(2)=XN1(2)
0108      Y(2)=YN1(2)
0109      NT=NT+1
0110      IF(NT.EQ.99)NT=NT+1
0111      CALL IPOINT(XC,YC,X,Y,NT,IND)
0112      IF(IND.EQ.0)THEN
0113      CALL PLOTTER(X,Y,2,-90,0,2,NT)
0114      ENDIF
0115      X(1)=XN1(2)
0116      Y(1)=YN1(2)
0117      X(2)=XN1(3)
0118      Y(2)=YN1(3)
0119      NT=NT+1
0120      IF(NT.EQ.99)NT=NT+1
0121      CALL IPOINT(XC,YC,X,Y,NT,IND)
0122      IF(IND.EQ.0)THEN
0123      CALL PLOTTER(X,Y,2,-90,0,2,NT)
0124      ENDIF
0125      X(1)=XN1(3)
0126      Y(1)=YN1(3)
0127      X(2)=XN1(4)
0128      Y(2)=YN1(4)
0129      NT=NT+1
0130      IF(NT.EQ.99)NT=NT+1
0131      CALL IPOINT(XC,YC,X,Y,NT,IND)
0132      IF(IND.EQ.0)THEN
0133      CALL PLOTTER(X,Y,2,-90,0,2,NT)
0134      ENDIF
0135      X(1)=XN1(4)
0136      Y(1)=YN1(4)
0137      X(2)=XN1(1)
0138      Y(2)=YN1(1)
0139      NT=NT+1
0140      IF(NT.EQ.99)NT=NT+1
0141      CALL IPOINT(XC,YC,X,Y,NT,IND)
0142      IF(IND.EQ.0)THEN
0143      CALL PLOTTER(X,Y,2,-90,0,2,NT)
0144      ENDIF
0145      ENDIF
0146      IF(ITP.EQ.4)THEN
0147  C
0148  C      READ: X3P,Y3P,X4P,Y4P = POINT 3' AND 4' OF BT4 BLOCK
0149  C
0150      READ(9,*)XN1(3),YN1(3),XN1(4),YN1(4)

```

```

0151             IF(IGEOM.NE.1)THEN
0152             X(1)=XN1(1)
0153             Y(1)=YN1(1)
0154             X(2)=XN1(2)
0155             Y(2)=YN1(2)
0156             NT=NT+1
0157             IF(NT.EQ.99)NT=NT+1
0158             CALL IPOINT(XC,YC,X,Y,NT,IND)
0159             IF(IND.EQ.0)THEN
0160             CALL PLOTTER(X,Y,2,-90,0,2,NT)
0161             ENDIF
0162             X(1)=XN1(2)
0163             Y(1)=YN1(2)
0164             X(2)=XN1(3)
0165             Y(2)=YN1(3)
0166             NT=NT+1
0167             IF(NT.EQ.99)NT=NT+1
0168             CALL IPOINT(XC,YC,X,Y,NT,IND)
0169             IF(IND.EQ.0)THEN
0170             CALL PLOTTER(X,Y,2,-90,0,2,NT)
0171             ENDIF
0172             X(1)=XN1(3)
0173             Y(1)=YN1(3)
0174             X(2)=XN1(4)
0175             Y(2)=YN1(4)
0176             NT=NT+1
0177             IF(NT.EQ.99)NT=NT+1
0178             CALL IPOINT(XC,YC,X,Y,NT,IND)
0179             IF(IND.EQ.0)THEN
0180             CALL PLOTTER(X,Y,2,-90,0,2,NT)
0181             ENDIF
0182             X(1)=XN1(4)
0183             Y(1)=YN1(4)
0184             X(2)=XN1(1)
0185             Y(2)=YN1(1)
0186             NT=NT+1
0187             IF(NT.EQ.99)NT=NT+1
0188             CALL IPOINT(XC,YC,X,Y,NT,IND)
0189             IF(IND.EQ.0)THEN
0190             CALL PLOTTER(X,Y,2,-90,0,2,NT)
0191             ENDIF
0192             ENDIF
0193             ENDIF
0194             ENDIF

```

```

0195      5      CONTINUE
0196      C
0197      C      IN PLOTTER 99 INDICATES LAST PLOT
0198      C
0199      IF(IGEOM.NE.1)THEN
0200      NT=99
0201      X(1)=0.0
0202      Y(1)=0.0
0203      Y(2)=0.00001
0204      X(2)=0.00001
0205      CALL PLOTTER(X,Y,2,-90,0,3,NT)
0206      ENDIF
0207      C
0208      C      MODE INFORMATION PART
0209      C
0210      C      READ: LMD = NUMBER OF QUADRILATERAL CELLS
0211      C      NM = NUMBER OF SHEET IMPEDANCE SEGMENTS
0212      C
0213      READ(9,*)LMD,NM
0214      C
0215      C      INITIALIZE PLOT NUMBER
0216      C
0217      NT=0
0218      C
0219      C      PLOT SEGMENTS
0220      C
0221      IF(IGEOM.NE.0)THEN
0222      DO 21 J1=1,NM
0223      C
0224      C      READ: X(1),Y(1),X(2),Y(2) = POINT 1 AND POINT 2 OF SEGMENT
0225      C
0226      READ(9,*)X(1),Y(1),X(2),Y(2)
0227      IF(NM.NE.1)NT=NT+1
0228      IF(NT.EQ.99)NT=NT+1
0229      IF(NM.EQ.1.AND.LMD.EQ.0)NT=0
0230      CALL PLOTTER(X,Y,2,-90,0,1,NT)
0231      21      CONTINUE
0232      C
0233      C      PLOT QUADRILATERAL CELLS
0234      C
0235      DO 20 J=1,LMD
0236      DO 30 I=1,4
0237      READ(9,*)XN1(I),YN1(I)
0238      30      CONTINUE

```

```

0239      X(1)=XN1(1)
0240      Y(1)=YN1(1)
0241      X(2)=XN1(2)
0242      Y(2)=YN1(2)
0243      NT=NT+1
0244      IF(NT.EQ.99)NT=NT+1
0245      CALL IPOINT(XC,YC,X,Y,NT,IND)
0246      IF(IND.EQ.0)THEN
0247      CALL PLOTTER(X,Y,2,-90,0,2,NT)
0248      ENDIF
0249      X(1)=XN1(2)
0250      Y(1)=YN1(2)
0251      X(2)=XN1(3)
0252      Y(2)=YN1(3)
0253      NT=NT+1
0254      IF(NT.EQ.99)NT=NT+1
0255      CALL IPOINT(XC,YC,X,Y,NT,IND)
0256      IF(IND.EQ.0)THEN
0257      CALL PLOTTER(X,Y,2,-90,0,2,NT)
0258      ENDIF
0259      X(1)=XN1(3)
0260      Y(1)=YN1(3)
0261      X(2)=XN1(4)
0262      Y(2)=YN1(4)
0263      NT=NT+1
0264      IF(NT.EQ.99)NT=NT+1
0265      CALL IPOINT(XC,YC,X,Y,NT,IND)
0266      IF(IND.EQ.0)THEN
0267      CALL PLOTTER(X,Y,2,-90,0,2,NT)
0268      ENDIF
0269      X(1)=XN1(4)
0270      Y(1)=YN1(4)
0271      X(2)=XN1(1)
0272      Y(2)=YN1(1)
0273      NT=NT+1
0274      IF(NT.EQ.99)NT=NT+1
0275      CALL IPOINT(XC,YC,X,Y,NT,IND)
0276      IF(IND.EQ.0)THEN
0277      CALL PLOTTER(X,Y,2,-90,0,2,NT)
0278      ENDIF
0279      20  CONTINUE
0280      IF(IGEOM.NE.0)THEN
0281      C
0282      C      IN PLOTTER 99 INDICATES LAST PLOT

```

```
0283      C
0284          NT=99
0285          X(1)=0.0
0286          Y(1)=0.0
0287          Y(2)=0.00001
0288          X(2)=0.00001
0289          CALL PLOTTER(X,Y,2,-90,0,3,NT)
0290      ENDIF
0291      ENDIF
0292      STOP
0293      END
```

## Appendix C

### Subroutine PATP for Generating Pattern Plots

```
C      PROGRAM PATP GENERATES A PATTERN PLOT (i.e. ECHO WIDTH
C      VS. PATTERN ANGLE)
C
C      DIMENSION WM(361),PH(361),PHS(361)
C
C      READ: FMHZ = FREQUENCY IN MEGAHERTZ
C      IPAT = 0 FOR BACKSCATTER PLOTS
C      1 FOR BISTATIC PLOTS
C      ISTEP = NO. OF PATTERN POINTS GOING FROM 0 TO 360
C      PHID = THE ANGLE OF THE INCIDENT WAVE IN DEGREES
C      FOR BISTATIC PATTERNS
C      NTOTT = THE TOTAL NO. OF MM MODES
C
C      READ(7,*)FMHZ,IPAT,ISTEP,PHID,NTOTT
DO100I=1,ISTEP
C
C      READ: PH(I) = ANGLE OF SCATTERED WAVE IN DEGREES
C      WM(I) =ECHO WIDTH IN dB OVER A METER
C      PHS(I) = PHASE IN DEGREES OF SCATTERED FIELD
C
C      READ(7,*)PH(I),WM(I),PHS(I)
      100 CONTINUE
CALLPLOTTER(PH,WM,NSTEP,-90,0,1,0)
STOP
END
```



# Appendix D

## Output for Example 1

```
*****THE OHIO STATE UNIVERSITY*****  
PLANE WAVE SCATTERING BY A GENERAL CYLINDER  
****EXAMPLE 1****
```

```
COMMAND PRC: PRINT COMMANDS
```

```
**** LISTING OF COMMANDS AND INPUTS ****
```

```
COMMAND RUN: RUN DATA
```

```
COMMAND MDG: MODE GEOMETRY
```

```
COMMAND ACU: ACCURACY PARAMETERS
```

```
INTM =16   INT = 6   SEGM =.150   SEGC =.150
```

```
COMMAND FMZ: FREQUENCY
```

```
FMHZ =   300.0000
```

```
COMMAND POL: POLARIZATION TYPE
```

```
NPOL =0
```

```
COMMAND SCP: SCATTERING PATTERN
```

```
IPAT = 0   PHID = 90.00   STEP = 10.00
```

```
COMMAND BT1: BLOCK TYPE 1
```

```
X1 = -0.500   Y1 = 0.000   X2 = 0.500   Y2 = 0.000
```

IZSHTR = 1 IZSHTI = 1  
ZSHT1 =(0.0E+00,0.0E+00) ZSHT2 =(0.0E+00,0.0E+00)

COMMAND END: END OF INPUT DATA

SUMMARY OF RUN CONTROL PARAMETERS:

NGO; PARAMETER TO CONTINUE RUN = 1  
NPOL; INDICATOR FOR POLARIZATION TYPE = 0  
IPAT; INDICATOR FOR PATTERN TYPE = 0  
PHID; DIRECTION OF INCIDENT WAVE IN DEG. = 90.0  
STEP; INCREMENT OF PATTERN ANGLE IN DEG. = 10.0  
INF; INDICATOR FOR INTERNAL FIELDS = 0  
INT; CONDUCTOR INTEGRATION SEGMENTATIONS = 6  
INTM; MATERIAL SELF-ELEMENT INTEGRATION SEGMENTATIONS = 16  
IZWR; INDICATOR TO WRITE Z-MATRIX = 0  
ICWR; INDICATOR TO WRITE CURRENTS AND RHS VECTOR = 0  
IRDG; INDICATOR FOR INPUT TYPE = 1  
IDIE; INDICATOR FOR DIELECTRIC = 0  
IFER; INDICATOR FOR FERRITE = 0  
FHMZ; FREQUENCY IN MHZ = 300.0000  
WV; WAVELENGTH IN METERS = 1.0000  
SEGM; MAXIMUM SEGMENT SIZE IN MAT. WV = 0.150  
SEGC; MAXIMUM SEGMENT SIZE OF CONDUCTOR MODES = 0.150  
IMODE; INDICATOR TO PRINT MODE INFORMATION = 1

GEOMETRY FOR THE 1 BUILDING BLOCKS:  
(LINEAR DIMENSIONS IN METERS)

GEOMETRY FOR BUILDING BLOCK 1

BLOCK TYPE = 1

| PT. | X       | Y      |
|-----|---------|--------|
| 1   | -0.5000 | 0.0000 |
| 2   | 0.5000  | 0.0000 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
IMAGINARY PART SHEET IMPEDANCE TAPER TYPE = 1  
ZSHT1 =(0.0E+00,0.0E+00) ZSHT2 =(0.0E+00,0.0E+00)  
NO. SHEET IMPEDANCE SEGMENTS = 7

SUMMARY OF MODES:

NO. SHEET IMPEDANCE OR CONDUCTOR MODES = 7  
NO. DIELECTRIC MODES = 0  
NO. FERRITE MODES = 0  
TOTAL NO. MODES = 7

CONDUCTOR ENDPOINT COORDINATES :

| N = POINT NO. | X(N)    | Y(N)   |
|---------------|---------|--------|
| 1             | -0.5000 | 0.0000 |
| 2             | -0.3571 | 0.0000 |
| 3             | -0.2143 | 0.0000 |
| 4             | -0.0714 | 0.0000 |
| 5             | 0.0714  | 0.0000 |
| 6             | 0.2143  | 0.0000 |
| 7             | 0.3571  | 0.0000 |
| 8             | 0.5000  | 0.0000 |

CONDUCTOR MODE STRIP SEGMENTS:

| I | IA(I) | IB(I) | D(I)  | ZSH1(I)               | ZSH2(I)               |
|---|-------|-------|-------|-----------------------|-----------------------|
| 1 | 1     | 2     | 0.143 | (0.000E+00,0.000E+00) | (0.000E+00,0.000E+00) |
| 2 | 2     | 3     | 0.143 | (0.000E+00,0.000E+00) | (0.000E+00,0.000E+00) |
| 3 | 3     | 4     | 0.143 | (0.000E+00,0.000E+00) | (0.000E+00,0.000E+00) |
| 4 | 4     | 5     | 0.143 | (0.000E+00,0.000E+00) | (0.000E+00,0.000E+00) |
| 5 | 5     | 6     | 0.143 | (0.000E+00,0.000E+00) | (0.000E+00,0.000E+00) |
| 6 | 6     | 7     | 0.143 | (0.000E+00,0.000E+00) | (0.000E+00,0.000E+00) |
| 7 | 7     | 8     | 0.143 | (0.000E+00,0.000E+00) | (0.000E+00,0.000E+00) |

CPU TO GET Z-MATRIX = 0.06 SEC

BACKSCATTER PATTERN: PHI INCIDENT = PHI SCAT.

| PHI S(DEG) | ECHO WIDTH(M) | ECHO WIDTH(DB/M) | FIELD | PHASE(DEG) |
|------------|---------------|------------------|-------|------------|
| 0.00       | 0.1764        | -7.5358          | 0.168 | 124.12     |
| 10.00      | 0.1747        | -7.5765          | 0.167 | 118.55     |
| 20.00      | 0.1756        | -7.5544          | 0.167 | 101.17     |
| 30.00      | 0.2043        | -6.8971          | 0.180 | 73.12      |
| 40.00      | 0.2736        | -5.6286          | 0.209 | 42.71      |
| 50.00      | 0.2528        | -5.9730          | 0.201 | 11.77      |
| 60.00      | 0.1463        | -8.3469          | 0.153 | -61.26     |
| 70.00      | 1.1391        | 0.5656           | 0.426 | -126.36    |
| 80.00      | 4.1944        | 6.2267           | 0.817 | -141.04    |
| 90.00      | 6.2232        | 7.9402           | 0.995 | -144.38    |
| 100.00     | 4.1944        | 6.2267           | 0.817 | -141.04    |
| 110.00     | 1.1391        | 0.5656           | 0.426 | -126.36    |
| 120.00     | 0.1463        | -8.3469          | 0.153 | -61.26     |

|        |        |         |       |         |
|--------|--------|---------|-------|---------|
| 130.00 | 0.2528 | -5.9730 | 0.201 | 11.77   |
| 140.00 | 0.2736 | -5.6286 | 0.209 | 42.71   |
| 150.00 | 0.2043 | -6.8971 | 0.180 | 73.12   |
| 160.00 | 0.1756 | -7.5544 | 0.167 | 101.17  |
| 170.00 | 0.1747 | -7.5765 | 0.167 | 118.55  |
| 180.00 | 0.1764 | -7.5358 | 0.168 | 124.12  |
| 190.00 | 0.1747 | -7.5765 | 0.167 | 118.55  |
| 200.00 | 0.1756 | -7.5544 | 0.167 | 101.17  |
| 210.00 | 0.2043 | -6.8971 | 0.180 | 73.12   |
| 220.00 | 0.2736 | -5.6286 | 0.209 | 42.71   |
| 230.00 | 0.2528 | -5.9730 | 0.201 | 11.77   |
| 240.00 | 0.1463 | -8.3469 | 0.153 | -61.26  |
| 250.00 | 1.1391 | 0.5656  | 0.426 | -126.36 |
| 260.00 | 4.1944 | 6.2267  | 0.817 | -141.04 |
| 270.00 | 6.2232 | 7.9402  | 0.995 | -144.38 |
| 280.00 | 4.1944 | 6.2267  | 0.817 | -141.04 |
| 290.00 | 1.1391 | 0.5656  | 0.426 | -126.36 |
| 300.00 | 0.1463 | -8.3469 | 0.153 | -61.26  |
| 310.00 | 0.2528 | -5.9730 | 0.201 | 11.77   |
| 320.00 | 0.2736 | -5.6286 | 0.209 | 42.71   |
| 330.00 | 0.2043 | -6.8971 | 0.180 | 73.12   |
| 340.00 | 0.1756 | -7.5545 | 0.167 | 101.17  |
| 350.00 | 0.1747 | -7.5765 | 0.167 | 118.55  |
| 360.00 | 0.1764 | -7.5358 | 0.168 | 124.12  |

CPU TIME TO SOLVE CURRENTS AND E.W. = 0.19 SEC

TOTAL CPU TIME= 0.25 SEC

# Appendix E

## Output for Example 2

```
*****THE OHIO STATE UNIVERSITY*****  
PLANE WAVE SCATTERING BY A GENERAL CYLINDER  
****EXAMPLE 2****
```

```
COMMAND PRC: PRINT COMMANDS  
**** LISTING OF COMMANDS AND INPUTS ****
```

```
COMMAND RUN: RUN DATA
```

```
COMMAND MDG: MODE GEOMETRY
```

```
COMMAND ACU: ACCURACY PARAMETERS  
INTM =16   INT = 6   SEGM =.150   SEGC =.150
```

```
COMMAND FMZ: FREQUENCY  
FMHZ =   300.0000
```

```
COMMAND WRI: WRITE INDICATORS  
IZWR = 0   ICWR = 0
```

```
COMMAND POL: POLARIZATION TYPE  
NPOL =1
```

```
COMMAND SCP: SCATTERING PATTERN
```

IPAT = 0 PHID = 90.00 STEP = 10.00

COMMAND BT1: BLOCK TYPE 1

X1 = -0.500 Y1 = 0.000 X2 = 0.500 Y2 = 0.000

IZSHTR = 1 IZSHTI = 1

ZSHT1 =(0.1E+01,0.1E+02) ZSHT2 =(0.1E+03,0.1E+02)

COMMAND END: END OF INPUT DATA

SUMMARY OF RUN CONTROL PARAMETERS:

NGO; PARAMETER TO CONTINUE RUN = 1

NPOL; INDICATOR FOR POLARIZATION TYPE = 1

IPAT; INDICATOR FOR PATTERN TYPE = 0

PHID; DIRECTION OF INCIDENT WAVE IN DEG. = 90.0

STEP; INCREMENT OF PATTERN ANGLE IN DEG. = 10.0

INF; INDICATOR FOR INTERNAL FIELDS = 0

INT; CONDUCTOR INTEGRATION SEGMENTATIONS = 6

INTM; MATERIAL SELF-ELEMENT INTEGRATION SEGMENTATIONS = 16

IZWR; INDICATOR TO WRITE Z-MATRIX = 0

ICWR; INDICATOR TO WRITE CURRENTS AND RHS VECTOR = 0

IRDG; INDICATOR FOR INPUT TYPE = 1

IDIE; INDICATOR FOR DIELECTRIC = 0

IFER; INDICATOR FOR FERRITE = 0

FHMZ; FREQUENCY IN MHZ = 300.0000

WV; WAVELENGTH IN METERS = 1.0000

SEGM; MAXIMUM SEGMENT SIZE IN MAT. WV = 0.150

SEGC; MAXIMUM SEGMENT SIZE OF CONDUCTOR MODES = 0.150

IMODE; INDICATOR TO PRINT MODE INFORMATION = 1

GEOMETRY FOR THE 1 BUILDING BLOCKS:

(LINEAR DIMENSIONS IN METERS)

GEOMETRY FOR BUILDING BLOCK 1

BLOCK TYPE = 1

| PT. | X       | Y      |
|-----|---------|--------|
| 1   | -0.5000 | 0.0000 |
| 2   | 0.5000  | 0.0000 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1

IMAGINARY PART SHEET IMPEDANCE TAPER TYPE = 1

ZSHT1 =(0.1E+01,0.1E+02) ZSHT2 =(0.1E+03,0.1E+02)

NO. SHEET IMPEDANCE SEGMENTS = 7

SUMMARY OF MODES:

NO. SHEET IMPEDANCE OR CONDUCTOR MODES = 6  
 NO. DIELECTRIC MODES = 0  
 NO. FERRITE MODES = 0  
 TOTAL NO. MODES = 6

CONDUCTOR ENDPOINT COORDINATES :

| N = POINT NO. | X(N)    | Y(N)   |
|---------------|---------|--------|
| 1             | -0.5000 | 0.0000 |
| 2             | -0.3571 | 0.0000 |
| 3             | -0.2143 | 0.0000 |
| 4             | -0.0714 | 0.0000 |
| 5             | 0.0714  | 0.0000 |
| 6             | 0.2143  | 0.0000 |
| 7             | 0.3571  | 0.0000 |
| 8             | 0.5000  | 0.0000 |

CONDUCTOR MODE STRIP SEGMENTS:

| I | IA(I) | IB(I) | D(I)  | ZSH1(I)               | ZSH2(I)               |
|---|-------|-------|-------|-----------------------|-----------------------|
| 1 | 1     | 2     | 0.143 | (0.100E+01,0.100E+02) | (0.151E+02,0.100E+02) |
| 2 | 2     | 3     | 0.143 | (0.151E+02,0.100E+02) | (0.293E+02,0.100E+02) |
| 3 | 3     | 4     | 0.143 | (0.293E+02,0.100E+02) | (0.434E+02,0.100E+02) |
| 4 | 4     | 5     | 0.143 | (0.434E+02,0.100E+02) | (0.576E+02,0.100E+02) |
| 5 | 5     | 6     | 0.143 | (0.576E+02,0.100E+02) | (0.717E+02,0.100E+02) |
| 6 | 6     | 7     | 0.143 | (0.717E+02,0.100E+02) | (0.859E+02,0.100E+02) |
| 7 | 7     | 8     | 0.143 | (0.859E+02,0.100E+02) | (0.100E+03,0.100E+02) |

CONDUCTOR MODE NUMBERS:

| I = MODE | I1(I) | I2(I) | I3(I) |
|----------|-------|-------|-------|
| 1        | 1     | 2     | 3     |
| 2        | 2     | 3     | 4     |
| 3        | 3     | 4     | 5     |
| 4        | 4     | 5     | 6     |
| 5        | 5     | 6     | 7     |
| 6        | 6     | 7     | 8     |

CPU TO GET Z-MATRIX = 0.04 SEC

BACKSCATTER PATTERN: PHI INCIDENT = PHI SCAT.

PHI S(DEG) ECHO WIDTH(M) ECHO WIDTH(DB/M) |FIELD| PHASE(DEG)

|        |        |          |       |         |
|--------|--------|----------|-------|---------|
| 0.00   | 0.0000 | 0.0000   | 0.000 | 0.00    |
| 10.00  | 0.0017 | -27.7156 | 0.016 | -140.48 |
| 20.00  | 0.0268 | -15.7247 | 0.065 | -134.67 |
| 30.00  | 0.1250 | -9.0296  | 0.141 | -125.77 |
| 40.00  | 0.3028 | -5.1886  | 0.220 | -113.97 |
| 50.00  | 0.3819 | -4.1803  | 0.247 | -96.03  |
| 60.00  | 0.2517 | -5.9905  | 0.200 | -51.66  |
| 70.00  | 0.7070 | -1.5060  | 0.335 | 17.15   |
| 80.00  | 2.4317 | 3.8591   | 0.622 | 40.86   |
| 90.00  | 3.4343 | 5.3584   | 0.739 | 48.50   |
| 100.00 | 2.0274 | 3.0693   | 0.568 | 49.47   |
| 110.00 | 0.3493 | -4.5684  | 0.236 | 40.91   |
| 120.00 | 0.0354 | -14.5043 | 0.075 | -83.09  |
| 130.00 | 0.1961 | -7.0745  | 0.177 | -118.50 |
| 140.00 | 0.1649 | -7.8279  | 0.162 | -129.00 |
| 150.00 | 0.0637 | -11.9571 | 0.101 | -138.43 |
| 160.00 | 0.0127 | -18.9604 | 0.045 | -147.24 |
| 170.00 | 0.0008 | -31.1412 | 0.011 | -153.70 |
| 180.00 | 0.0000 | -99.9900 | 0.000 | -156.08 |
| 190.00 | 0.0008 | -31.1412 | 0.011 | -153.70 |
| 200.00 | 0.0127 | -18.9604 | 0.045 | -147.24 |
| 210.00 | 0.0637 | -11.9571 | 0.101 | -138.43 |
| 220.00 | 0.1649 | -7.8279  | 0.162 | -129.00 |
| 230.00 | 0.1961 | -7.0745  | 0.177 | -118.50 |
| 240.00 | 0.0354 | -14.5043 | 0.075 | -83.09  |
| 250.00 | 0.3493 | -4.5684  | 0.236 | 40.91   |
| 260.00 | 2.0274 | 3.0693   | 0.568 | 49.47   |
| 270.00 | 3.4343 | 5.3584   | 0.739 | 48.50   |
| 280.00 | 2.4317 | 3.8591   | 0.622 | 40.86   |
| 290.00 | 0.7070 | -1.5060  | 0.335 | 17.15   |
| 300.00 | 0.2517 | -5.9905  | 0.200 | -51.66  |
| 310.00 | 0.3819 | -4.1803  | 0.247 | -96.03  |
| 320.00 | 0.3028 | -5.1886  | 0.220 | -113.97 |
| 330.00 | 0.1250 | -9.0296  | 0.141 | -125.77 |
| 340.00 | 0.0268 | -15.7247 | 0.065 | -134.67 |
| 350.00 | 0.0017 | -27.7155 | 0.016 | -140.48 |
| 360.00 | 0.0000 | -99.9900 | 0.000 | -142.52 |

CPU TIME TO SOLVE CURRENTS AND E.W. = 0.32 SEC

TOTAL CPU TIME= 0.36 SEC



# Appendix F

## Output for Example 3

\*\*\*\*\*THE OHIO STATE UNIVERSITY\*\*\*\*\*  
PLANE WAVE SCATTERING BY A GENERAL CYLINDER  
\*\*\*\*\*EXAMPLE 3\*\*\*\*\*

COMMAND PRC: PRINT COMMANDS  
\*\*\*\* LISTING OF COMMANDS AND INPUTS \*\*\*\*

COMMAND RUN: RUN DATA

COMMAND MDG: MODE GEOMETRY

COMMAND ACU: ACCURACY PARAMETERS  
INTM =16 INT = 6 SEGM =.150 SEGC =.150

COMMAND FMZ: FREQUENCY  
FMHZ = 300.0000

COMMAND WRI: WRITE INDICATORS  
IZWR = 1 ICWR = 1

COMMAND POL: POLARIZATION TYPE  
NPOL =0

COMMAND SCP: SCATTERING PATTERN  
IPAT = 1 PHID = 90.00 STEP = 10.00

COMMAND BT3: BLOCK TYPE 3

X1 = 0.000 Y1 = 0.000 X2 = 0.250 Y2 = 0.000  
X3 = 0.250 Y3 = 0.050 X4 = 0.000 Y4 = 0.050  
ER = 1.500 TDE = 0.1E-01 UR = 2.000 TDM = 0.0E+00  
IZSHTR = 1 IZSHTI = 1  
ZSHT1 = (0.0E+00, 0.0E+00) ZSHT2 = (0.0E+00, 0.0E+00)

COMMAND END: END OF INPUT DATA

SUMMARY OF RUN CONTROL PARAMETERS:

NGO; PARAMETER TO CONTINUE RUN = 1  
NPOL; INDICATOR FOR POLARIZATION TYPE = 0  
IPAT; INDICATOR FOR PATTERN TYPE = 1  
PHID; DIRECTION OF INCIDENT WAVE IN DEG. = 90.0  
STEP; INCREMENT OF PATTERN ANGLE IN DEG. = 10.0  
INF; INDICATOR FOR INTERNAL FIELDS = 0  
INT; CONDUCTOR INTEGRATION SEGMENTATIONS = 6  
INTM; MATERIAL SELF-ELEMENT INTEGRATION SEGMENTATIONS = 16  
IZWR; INDICATOR TO WRITE Z-MATRIX = 1  
ICWR; INDICATOR TO WRITE CURRENTS AND RHS VECTOR = 1  
IRDG; INDICATOR FOR INPUT TYPE = 1  
IDIE; INDICATOR FOR DIELECTRIC = 1  
IFER; INDICATOR FOR FERRITE = 1  
FHMZ; FREQUENCY IN MHZ = 300.0000  
WV; WAVELENGTH IN METERS = 1.0000  
SEGM; MAXIMUM SEGMENT SIZE IN MAT. WV = 0.150  
SEGC; MAXIMUM SEGMENT SIZE OF CONDUCTOR MODES = 0.150  
IMODE; INDICATOR TO PRINT MODE INFORMATION = 1

GEOMETRY FOR THE 1 BUILDING BLOCKS:  
(LINEAR DIMENSIONS IN METERS)

GEOMETRY FOR BUILDING BLOCK 1  
BLOCK TYPE = 3

| PT. | X      | Y      |
|-----|--------|--------|
| 1   | 0.0000 | 0.0000 |
| 2   | 0.2500 | 0.0000 |
| 3   | 0.2500 | 0.0500 |
| 4   | 0.0000 | 0.0500 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)

ER = 1.500 TDE = .1E-01 UR = 2.000 TDM = .0E+00  
 NO. OF MATERIAL CELLS = 3  
 NO. SHEET IMPEDANCE SEGMENTS = 3

SUMMARY OF MODES:

NO. SHEET IMPEDANCE OR CONDUCTOR MODES = 3  
 NO. DIELECTRIC MODES = 3  
 NO. FERRITE MODES = 6  
 TOTAL NO. MODES = 12

CONDUCTOR ENDPOINT COORDINATES :

| N = POINT NO. | X(N)   | Y(N)   |
|---------------|--------|--------|
| 1             | 0.0000 | 0.0000 |
| 2             | 0.0833 | 0.0000 |
| 3             | 0.1667 | 0.0000 |
| 4             | 0.2500 | 0.0000 |

CONDUCTOR MODE STRIP SEGMENTS:

| I | IA(I) | IB(I) | D(I)  | ZSH1(I)          | ZSH2(I)          |
|---|-------|-------|-------|------------------|------------------|
| 1 | 1     | 2     | 0.083 | (.0E+00, .0E+00) | (.0E+00, .0E+00) |
| 2 | 2     | 3     | 0.083 | (.0E+00, .0E+00) | (.0E+00, .0E+00) |
| 3 | 3     | 4     | 0.083 | (.0E+00, .0E+00) | (.0E+00, .0E+00) |

MATERIAL CELL ENDPOINT COORDINATES :

| CELL | XD1   | YD1   | XD2   | YD2   | XD3   | YD3   | XD4   | YD4   |
|------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1    | 0.000 | 0.000 | 0.083 | 0.000 | 0.083 | 0.050 | 0.000 | 0.050 |
| 2    | 0.083 | 0.000 | 0.167 | 0.000 | 0.167 | 0.050 | 0.083 | 0.050 |
| 3    | 0.167 | 0.000 | 0.250 | 0.000 | 0.250 | 0.050 | 0.167 | 0.050 |

ELEMENTS OF THE IMPEDANCE MATRIX BY BLOCKS:

SZ = CONDUCTOR Z-POL CURRENTS

JZ = DIELECTRIC Z-POL CURRENTS

M13 = FERRITE SIDE 1 TO 3-POL CURRENTS

M42 = FERRITE SIDE 4 TO 2-POL CURRENTS

SZ/SZ BLOCK

| M | N | ML | NL | Z(M,N)                      |
|---|---|----|----|-----------------------------|
| 1 | 1 | 1  | 1  | ( 0.58546E+03, 0.84309E+03) |
| 1 | 2 | 1  | 2  | ( 0.54602E+03, 0.28595E+03) |

|   |   |   |   |   |              |               |
|---|---|---|---|---|--------------|---------------|
| 1 | 3 | 1 | 3 | ( | 0.43613E+03, | -0.61353E+02) |
| 2 | 1 | 2 | 1 | ( | 0.54602E+03, | 0.28595E+03)  |
| 2 | 2 | 2 | 2 | ( | 0.58546E+03, | 0.84309E+03)  |
| 2 | 3 | 2 | 3 | ( | 0.54602E+03, | 0.28595E+03)  |
| 3 | 1 | 3 | 1 | ( | 0.43613E+03, | -0.61353E+02) |
| 3 | 2 | 3 | 2 | ( | 0.54602E+03, | 0.28595E+03)  |
| 3 | 3 | 3 | 3 | ( | 0.58546E+03, | 0.84309E+03)  |

# SZ/JZ BLOCK

| M | N | ML | NL |   | Z(M,N)                     |
|---|---|----|----|---|----------------------------|
| 1 | 4 | 1  | 1  | ( | 0.57968E+03, 0.58690E+03)  |
| 1 | 5 | 1  | 2  | ( | 0.53722E+03, 0.21855E+03)  |
| 1 | 6 | 1  | 3  | ( | 0.42669E+03, -0.64074E+02) |
| 2 | 4 | 2  | 1  | ( | 0.53722E+03, 0.21855E+03)  |
| 2 | 5 | 2  | 2  | ( | 0.57968E+03, 0.58690E+03)  |
| 2 | 6 | 2  | 3  | ( | 0.53722E+03, 0.21855E+03)  |
| 3 | 4 | 3  | 1  | ( | 0.42694E+03, -0.61044E+02) |
| 3 | 5 | 3  | 2  | ( | 0.53722E+03, 0.21855E+03)  |
| 3 | 6 | 3  | 3  | ( | 0.57968E+03, 0.58690E+03)  |

# SZ/M BLOCKS

## SZ/M13

| M | N | ML | NL |   | Z(M,N)                     |
|---|---|----|----|---|----------------------------|
| 1 | 7 | 1  | 1  | ( | 0.83447E-06, -0.47684E-06) |
| 1 | 8 | 1  | 2  | ( | 0.15191E+01, -0.14522E+01) |
| 1 | 9 | 1  | 3  | ( | 0.11506E+01, -0.69977E+00) |
| 2 | 7 | 2  | 1  | ( | -0.15191E+01, 0.14522E+01) |
| 2 | 8 | 2  | 2  | ( | 0.83447E-06, -0.47684E-06) |
| 2 | 9 | 2  | 3  | ( | 0.15191E+01, -0.14522E+01) |
| 3 | 7 | 3  | 1  | ( | -0.11506E+01, 0.69977E+00) |
| 3 | 8 | 3  | 2  | ( | -0.15191E+01, 0.14522E+01) |
| 3 | 9 | 3  | 3  | ( | 0.71526E-06, 0.71526E-06)  |

## SZ/M42

| M | N  | ML | NL |   | Z(M,N)                     |
|---|----|----|----|---|----------------------------|
| 1 | 10 | 1  | 1  | ( | -0.38107E+01, 0.12191E+00) |
| 1 | 11 | 1  | 2  | ( | -0.87895E+00, 0.11598E+00) |
| 1 | 12 | 1  | 3  | ( | -0.18724E+00, 0.10600E+00) |

|   |    |   |   |                              |
|---|----|---|---|------------------------------|
| 2 | 10 | 2 | 1 | ( -0.87895E+00, 0.11598E+00) |
| 2 | 11 | 2 | 2 | ( -0.38107E+01, 0.12191E+00) |
| 2 | 12 | 2 | 3 | ( -0.87895E+00, 0.11598E+00) |
| 3 | 10 | 3 | 1 | ( -0.17289E+00, 0.11010E+00) |
| 3 | 11 | 3 | 2 | ( -0.87895E+00, 0.11598E+00) |
| 3 | 12 | 3 | 3 | ( -0.38107E+01, 0.12191E+00) |

#### JZ/SZ BLOCK

| M | N | ML | NL | Z(M,N)                       |
|---|---|----|----|------------------------------|
| 4 | 1 | 1  | 1  | ( 0.58485E+03, 0.62297E+03)  |
| 4 | 2 | 1  | 2  | ( 0.54546E+03, 0.23606E+03)  |
| 4 | 3 | 1  | 3  | ( 0.43506E+03, -0.72866E+02) |
| 5 | 1 | 2  | 1  | ( 0.54546E+03, 0.23606E+03)  |
| 5 | 2 | 2  | 2  | ( 0.58485E+03, 0.62297E+03)  |
| 5 | 3 | 2  | 3  | ( 0.54546E+03, 0.23606E+03)  |
| 6 | 1 | 3  | 1  | ( 0.43506E+03, -0.72866E+02) |
| 6 | 2 | 3  | 2  | ( 0.54546E+03, 0.23606E+03)  |
| 6 | 3 | 3  | 3  | ( 0.58485E+03, 0.62297E+03)  |

#### M/SZ BLOCK

##### M13/SZ

| M | N | ML | NL | Z(M,N)                       |
|---|---|----|----|------------------------------|
| 7 | 1 | 1  | 1  | ( 0.14901E-07, 0.27940E-08)  |
| 7 | 2 | 1  | 2  | ( 0.21273E+01, -0.39269E+00) |
| 7 | 3 | 1  | 3  | ( 0.11478E+01, -0.70601E+00) |
| 8 | 1 | 2  | 1  | ( -0.21273E+01, 0.39269E+00) |
| 8 | 2 | 2  | 2  | ( 0.25332E-06, -0.19558E-07) |
| 8 | 3 | 2  | 3  | ( 0.21273E+01, -0.39269E+00) |
| 9 | 1 | 3  | 1  | ( -0.11478E+01, 0.70601E+00) |
| 9 | 2 | 3  | 2  | ( -0.21273E+01, 0.39269E+00) |
| 9 | 3 | 3  | 3  | ( -0.73016E-06, 0.21420E-07) |

##### M42/SZ

| M  | N | ML | NL | Z(M,N)                       |
|----|---|----|----|------------------------------|
| 10 | 1 | 1  | 1  | ( 0.41039E+01, -0.12264E+00) |
| 10 | 2 | 1  | 2  | ( 0.74932E+00, -0.11849E+00) |
| 10 | 3 | 1  | 3  | ( 0.18053E+00, -0.10655E+00) |
| 11 | 1 | 2  | 1  | ( 0.74932E+00, -0.11849E+00) |

|    |   |   |   |                              |
|----|---|---|---|------------------------------|
| 11 | 2 | 2 | 2 | ( 0.41039E+01, -0.12264E+00) |
| 11 | 3 | 2 | 3 | ( 0.74932E+00, -0.11849E+00) |
| 12 | 1 | 3 | 1 | ( 0.18053E+00, -0.10655E+00) |
| 12 | 2 | 3 | 2 | ( 0.74932E+00, -0.11849E+00) |
| 12 | 3 | 3 | 3 | ( 0.41040E+01, -0.12264E+00) |

# JZ/JZ BLOCK

| M | N | ML | NL | Z(M,N)                       |
|---|---|----|----|------------------------------|
| 4 | 4 | 1  | 1  | ( 0.14497E+04, -0.27986E+05) |
| 4 | 5 | 1  | 2  | ( 0.54760E+03, 0.25165E+03)  |
| 4 | 6 | 1  | 3  | ( 0.43661E+03, -0.69206E+02) |
| 5 | 4 | 2  | 1  | ( 0.54760E+03, 0.25165E+03)  |
| 5 | 5 | 2  | 2  | ( 0.14497E+04, -0.27986E+05) |
| 5 | 6 | 2  | 3  | ( 0.54760E+03, 0.25165E+03)  |
| 6 | 4 | 3  | 1  | ( 0.43661E+03, -0.69206E+02) |
| 6 | 5 | 3  | 2  | ( 0.54760E+03, 0.25165E+03)  |
| 6 | 6 | 3  | 3  | ( 0.14497E+04, -0.27986E+05) |

# JZ/M BLOCKS

## JZ/M13

| M | N | ML | NL | Z(M,N)                       |
|---|---|----|----|------------------------------|
| 4 | 7 | 1  | 1  | ( 0.71054E-13, -0.35527E-13) |
| 4 | 8 | 1  | 2  | ( 0.22985E+01, -0.39331E+00) |
| 4 | 9 | 1  | 3  | ( 0.11571E+01, -0.71054E+00) |
| 5 | 7 | 2  | 1  | ( -0.22985E+01, 0.39331E+00) |
| 5 | 8 | 2  | 2  | ( 0.47684E-06, -0.35527E-13) |
| 5 | 9 | 2  | 3  | ( 0.22985E+01, -0.39331E+00) |
| 6 | 7 | 3  | 1  | ( -0.11571E+01, 0.71054E+00) |
| 6 | 8 | 3  | 2  | ( -0.22985E+01, 0.39331E+00) |
| 6 | 9 | 3  | 3  | ( -0.47684E-06, 0.00000E+00) |

## JZ/M42

| M | N  | ML | NL | Z(M,N)                        |
|---|----|----|----|-------------------------------|
| 4 | 10 | 1  | 1  | ( -0.95367E-06, 0.47684E-06)  |
| 4 | 11 | 1  | 2  | ( -0.65828E-07, 0.40651E-06)  |
| 4 | 12 | 1  | 3  | ( -0.91123E-07, 0.58820E-06)  |
| 5 | 10 | 2  | 1  | ( -0.53382E-07, -0.40651E-06) |
| 5 | 11 | 2  | 2  | ( 0.85265E-13, 0.47684E-06)   |

|   |    |   |   |                              |
|---|----|---|---|------------------------------|
| 5 | 12 | 2 | 3 | ( 0.29180E-06, -0.70329E-07) |
| 6 | 10 | 3 | 1 | ( 0.31518E-07, -0.34978E-06) |
| 6 | 11 | 3 | 2 | ( -0.53382E-07, 0.70329E-07) |
| 6 | 12 | 3 | 3 | ( 0.47684E-06, 0.00000E+00)  |

# M/JZ BLOCKS

## M13/JZ

|   |   |   |   |                               |
|---|---|---|---|-------------------------------|
| 7 | 4 | 1 | 1 | ( -0.39977E-06, 0.44238E-08)  |
| 7 | 5 | 1 | 2 | ( 0.23035E+01, -0.39363E+00)  |
| 7 | 6 | 1 | 3 | ( 0.11674E+01, -0.70715E+00)  |
| 8 | 4 | 2 | 1 | ( -0.23035E+01, 0.39363E+00)  |
| 8 | 5 | 2 | 2 | ( -0.11912E-05, -0.11365E-07) |
| 8 | 6 | 2 | 3 | ( 0.23035E+01, -0.39363E+00)  |
| 9 | 4 | 3 | 1 | ( -0.11674E+01, 0.70714E+00)  |
| 9 | 5 | 3 | 2 | ( -0.23035E+01, 0.39363E+00)  |
| 9 | 6 | 3 | 3 | ( 0.24168E-06, 0.22046E-07)   |

## M42/JZ

| M  | N | ML | NL | Z(M,N)                       |
|----|---|----|----|------------------------------|
| 10 | 4 | 1  | 1  | ( 0.16275E-06, -0.30923E-08) |
| 10 | 5 | 1  | 2  | ( -0.39649E-02, 0.21394E-04) |
| 10 | 6 | 1  | 3  | ( -0.20880E-02, 0.16314E-03) |
| 11 | 4 | 2  | 1  | ( 0.39649E-02, -0.21397E-04) |
| 11 | 5 | 2  | 2  | ( 0.43865E-06, -0.62864E-08) |
| 11 | 6 | 2  | 3  | ( -0.39649E-02, 0.21393E-04) |
| 12 | 4 | 3  | 1  | ( 0.20880E-02, -0.16314E-03) |
| 12 | 5 | 3  | 2  | ( 0.39649E-02, -0.21399E-04) |
| 12 | 6 | 3  | 3  | ( 0.43935E-06, -0.63883E-08) |

# M/M BLOCKS

## M13/M13

| M | N | ML | NL | Z(M,N)                       |
|---|---|----|----|------------------------------|
| 7 | 7 | 1  | 1  | ( 0.20633E-02, -0.16527E+00) |
| 7 | 8 | 1  | 2  | ( 0.18551E-02, -0.10846E-01) |
| 7 | 9 | 1  | 3  | ( 0.12637E-02, -0.35197E-02) |
| 8 | 7 | 2  | 1  | ( 0.18551E-02, -0.10846E-01) |
| 8 | 8 | 2  | 2  | ( 0.20633E-02, -0.16527E+00) |
| 8 | 9 | 2  | 3  | ( 0.18551E-02, -0.10846E-01) |
| 9 | 7 | 3  | 1  | ( 0.12637E-02, -0.35197E-02) |
| 9 | 8 | 3  | 2  | ( 0.18551E-02, -0.10846E-01) |

9 9 3 3 ( 0.20633E-02, -0.16527E+00)

M42/M13

| M  | N | ML | NL | Z(M,N)                       |
|----|---|----|----|------------------------------|
| 10 | 7 | 1  | 1  | ( 0.20490E-09, -0.25141E-08) |
| 10 | 8 | 1  | 2  | ( 0.21319E-09, 0.78991E-09)  |
| 10 | 9 | 1  | 3  | ( 0.18348E-09, 0.32728E-09)  |
| 11 | 7 | 2  | 1  | ( 0.22026E-09, 0.16386E-08)  |
| 11 | 8 | 2  | 2  | ( 0.20019E-09, -0.22878E-08) |
| 11 | 9 | 2  | 3  | ( 0.22026E-09, 0.75219E-09)  |
| 12 | 7 | 3  | 1  | ( 0.15990E-09, 0.28956E-09)  |
| 12 | 8 | 3  | 2  | ( 0.22969E-09, 0.21290E-08)  |
| 12 | 9 | 3  | 3  | ( 0.20019E-09, -0.23632E-08) |

M13/M42

| M | N  | ML | NL | Z(M,N)                        |
|---|----|----|----|-------------------------------|
| 7 | 10 | 1  | 1  | ( 0.10291E-10, -0.18782E-09)  |
| 7 | 11 | 1  | 2  | ( -0.18114E-10, -0.22820E-08) |
| 7 | 12 | 1  | 3  | ( -0.88652E-10, -0.22924E-09) |
| 8 | 10 | 2  | 1  | ( 0.21472E-09, -0.22820E-08)  |
| 8 | 11 | 2  | 2  | ( -0.21142E-10, -0.18782E-09) |
| 8 | 12 | 2  | 3  | ( -0.18114E-10, -0.41939E-09) |
| 9 | 10 | 3  | 1  | ( 0.37701E-09, 0.70208E-09)   |
| 9 | 11 | 3  | 2  | ( 0.21472E-09, -0.41939E-09)  |
| 9 | 12 | 3  | 3  | ( -0.54252E-11, 0.94377E-09)  |

M42/M42

| M  | N  | ML | NL | Z(M,N)                       |
|----|----|----|----|------------------------------|
| 10 | 10 | 1  | 1  | ( 0.20709E-02, -0.13336E+00) |
| 10 | 11 | 1  | 2  | ( 0.20008E-02, 0.12613E-01)  |
| 10 | 12 | 1  | 3  | ( 0.17994E-02, 0.30381E-02)  |
| 11 | 10 | 2  | 1  | ( 0.20008E-02, 0.12613E-01)  |
| 11 | 11 | 2  | 2  | ( 0.20709E-02, -0.13336E+00) |
| 11 | 12 | 2  | 3  | ( 0.20008E-02, 0.12613E-01)  |
| 12 | 10 | 3  | 1  | ( 0.17994E-02, 0.30381E-02)  |
| 12 | 11 | 3  | 2  | ( 0.20008E-02, 0.12613E-01)  |
| 12 | 12 | 3  | 3  | ( 0.20709E-02, -0.13336E+00) |



# RHS OR VOLTAGE VECTOR

| I  | V-MAG    | PHASE(DEG) |
|----|----------|------------|
| 1  | 1.000000 | 0.00       |
| 2  | 1.000000 | 0.00       |
| 3  | 1.000000 | 0.00       |
| 4  | 1.000000 | 9.00       |
| 5  | 1.000000 | 9.00       |
| 6  | 1.000000 | 9.00       |
| 7  | 0.000000 | -171.00    |
| 8  | 0.000000 | -171.00    |
| 9  | 0.000000 | -171.00    |
| 10 | 0.002653 | -171.00    |
| 11 | 0.002653 | -171.00    |
| 12 | 0.002653 | -171.00    |

# CURRENT OR SOLUTION VECTOR

| M  | I-MAG    | PHASE(DEG) |
|----|----------|------------|
| 1  | 0.000630 | -49.91     |
| 2  | 0.000223 | -25.41     |
| 3  | 0.000630 | -49.87     |
| 4  | 0.000017 | 154.02     |
| 5  | 0.000015 | 159.97     |
| 6  | 0.000017 | 154.01     |
| 7  | 0.007326 | -156.70    |
| 8  | 0.000008 | -100.13    |
| 9  | 0.007322 | 23.29      |
| 10 | 0.040133 | -114.74    |
| 11 | 0.037343 | -107.10    |
| 12 | 0.040147 | -114.73    |

BISTATIC PATTERN: PHI INCIDENT (DEG) = 90.00

PHI S(DEG) ECHO WIDTH(M) ECHO WIDTH(DB/M) |FIELD| PHASE(DEG)

|       |        |         |       |         |
|-------|--------|---------|-------|---------|
| 0.00  | 0.3548 | -4.5003 | 0.238 | -136.84 |
| 10.00 | 0.3707 | -4.3096 | 0.243 | -139.52 |
| 20.00 | 0.3942 | -4.0428 | 0.250 | -143.36 |
| 30.00 | 0.4243 | -3.7235 | 0.260 | -148.26 |
| 40.00 | 0.4591 | -3.3812 | 0.270 | -154.09 |
| 50.00 | 0.4958 | -3.0473 | 0.281 | -160.70 |
| 60.00 | 0.5306 | -2.7520 | 0.291 | -167.94 |
| 70.00 | 0.5596 | -2.5211 | 0.298 | -175.61 |
| 80.00 | 0.5789 | -2.3742 | 0.304 | 176.48  |

|        |        |         |       |         |
|--------|--------|---------|-------|---------|
| 90.00  | 0.5856 | -2.3237 | 0.305 | 168.55  |
| 100.00 | 0.5789 | -2.3736 | 0.304 | 160.85  |
| 110.00 | 0.5598 | -2.5200 | 0.298 | 153.60  |
| 120.00 | 0.5308 | -2.7504 | 0.291 | 147.06  |
| 130.00 | 0.4960 | -3.0452 | 0.281 | 141.44  |
| 140.00 | 0.4593 | -3.3786 | 0.270 | 136.96  |
| 150.00 | 0.4246 | -3.7206 | 0.260 | 133.78  |
| 160.00 | 0.3945 | -4.0396 | 0.251 | 132.05  |
| 170.00 | 0.3710 | -4.3063 | 0.243 | 131.83  |
| 180.00 | 0.3551 | -4.4970 | 0.238 | 133.14  |
| 190.00 | 0.3469 | -4.5976 | 0.235 | 135.93  |
| 200.00 | 0.3463 | -4.6058 | 0.235 | 140.08  |
| 210.00 | 0.3522 | -4.5318 | 0.237 | 145.45  |
| 220.00 | 0.3634 | -4.3965 | 0.240 | 151.82  |
| 230.00 | 0.3778 | -4.2279 | 0.245 | 158.98  |
| 240.00 | 0.3930 | -4.0564 | 0.250 | 166.72  |
| 250.00 | 0.4064 | -3.9106 | 0.254 | 174.78  |
| 260.00 | 0.4156 | -3.8133 | 0.257 | -177.06 |
| 270.00 | 0.4189 | -3.7793 | 0.258 | -169.05 |
| 280.00 | 0.4156 | -3.8137 | 0.257 | -161.43 |
| 290.00 | 0.4063 | -3.9114 | 0.254 | -154.43 |
| 300.00 | 0.3929 | -4.0577 | 0.250 | -148.27 |
| 310.00 | 0.3776 | -4.2296 | 0.245 | -143.15 |
| 320.00 | 0.3632 | -4.3987 | 0.240 | -139.22 |
| 330.00 | 0.3520 | -4.5343 | 0.237 | -136.59 |
| 340.00 | 0.3460 | -4.6086 | 0.235 | -135.32 |
| 350.00 | 0.3467 | -4.6007 | 0.235 | -135.42 |
| 360.00 | 0.3548 | -4.5003 | 0.238 | -136.84 |

TOTAL CPU TIME= 2.02 SEC

# Appendix G

## Output for Example 4

\*\*\*\*\*THE OHIO STATE UNIVERSITY\*\*\*\*\*  
PLANE WAVE SCATTERING BY A GENERAL CYLINDER  
\*\*\*\*EXAMPLE 4\*\*\*\*

COMMAND PRC: PRINT COMMANDS

\*\*\*\* LISTING OF COMMANDS AND INPUTS \*\*\*\*

COMMAND MDG: MODE GEOMETRY

COMMAND ACU: ACCURACY PARAMETERS

INTM =16 INT = 6 SEGM =.150 SEGC =.150

COMMAND FMZ: FREQUENCY

FMHZ = 300.0000

COMMAND WRI: WRITE INDICATORS

IZWR = 0 ICWR = 1

COMMAND POL: POLARIZATION TYPE

NPOL =1

COMMAND SCP: SCATTERING PATTERN

IPAT = 1 PHID = 45.00 STEP = 5.00

COMMAND BT3: BLOCK TYPE 3

X1 = 0.000 Y1 = 0.000 X2 = 0.000 Y2 = 0.500  
 X3 = 0.100 Y3 = 0.500 X4 = 0.100 Y4 = 0.100  
 ER = 3.000 TDE = 0.1E+00 UR = 1.000 TDM = 0.0E+00  
 IZSHTR = 1 IZSHTI = 1  
 ZSHT1 = (0.0E+00, 0.0E+00) ZSHT2 = (0.0E+00, 0.0E+00)

COMMAND BT3: BLOCK TYPE 3

X1 = 0.000 Y1 = 0.000 X2 = 0.500 Y2 = 0.000  
 X3 = 0.500 Y3 = 0.100 X4 = 0.100 Y4 = 0.100  
 ER = 3.000 TDE = 0.1E+00 UR = 1.000 TDM = 0.0E+00  
 IZSHTR = 1 IZSHTI = 1  
 ZSHT1 = (0.0E+00, 0.0E+00) ZSHT2 = (0.0E+00, 0.0E+00)

COMMAND END: END OF INPUT DATA

SUMMARY OF RUN CONTROL PARAMETERS:

NGO; PARAMETER TO CONTINUE RUN = 1  
 NPOL; INDICATOR FOR POLARIZATION TYPE = 1  
 IPAT; INDICATOR FOR PATTERN TYPE = 1  
 PHID; DIRECTION OF INCIDENT WAVE IN DEG. = 45.0  
 STEP; INCREMENT OF PATTERN ANGLE IN DEG. = 5.0  
 INF; INDICATOR FOR INTERNAL FIELDS = 0  
 INT; CONDUCTOR INTEGRATION SEGMENTATIONS = 6  
 INTM; MATERIAL SELF-ELEMENT INTEGRATION SEGMENTATIONS = 16  
 IZWR; INDICATOR TO WRITE Z-MATRIX = 0  
 ICWR; INDICATOR TO WRITE CURRENTS AND RHS VECTOR = 1  
 IRDG; INDICATOR FOR INPUT TYPE = 1  
 IDIE; INDICATOR FOR DIELECTRIC = 1  
 IFER; INDICATOR FOR FERRITE = 1  
 FHMZ; FREQUENCY IN MHZ = 300.0000  
 WV; WAVELENGTH IN METERS = 1.0000  
 SEGM; MAXIMUM SEGMENT SIZE IN MAT. WV = 0.150  
 SEGC; MAXIMUM SEGMENT SIZE OF CONDUCTOR MODES = 0.150  
 IMODE; INDICATOR TO PRINT MODE INFORMATION = 1

GEOMETRY FOR THE 2 BUILDING BLOCKS:  
 (LINEAR DIMENSIONS IN METERS)

GEOMETRY FOR BUILDING BLOCK 1  
 BLOCK TYPE = 3

| PT. | X      | Y      |
|-----|--------|--------|
| 1   | 0.0000 | 0.0000 |
| 2   | 0.0000 | 0.5000 |

3      0.1000      0.5000  
 4      0.1000      0.1000  
 REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
 IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
 ZSHT1 = (.00E+00, .00E+00)    ZSHT2 = (.00E+00, .00E+00)  
 ER = 3.000    TDE = .1E+00    UR = 1.000    TDM = .0E+00  
 NO. OF MATERIAL CELLS = 12  
 NO. SHEET IMPEDANCE SEGMENTS = 6

GEOMETRY FOR BUILDING BLOCK 2  
 BLOCK TYPE = 3

| PT. | X      | Y      |
|-----|--------|--------|
| 1   | 0.0000 | 0.0000 |
| 2   | 0.5000 | 0.0000 |
| 3   | 0.5000 | 0.1000 |
| 4   | 0.1000 | 0.1000 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
 IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
 ZSHT1 = (.00E+00, .00E+00)    ZSHT2 = (.00E+00, .00E+00)  
 ER = 3.000    TDE = .1E+00    UR = 1.000    TDM = .0E+00  
 NO. OF MATERIAL CELLS = 12  
 NO. SHEET IMPEDANCE SEGMENTS = 6

SUMMARY OF MODES:  
 NO. SHEET IMPEDANCE OR CONDUCTOR MODES = 11  
 NO. DIELECTRIC MODES = 48  
 NO. FERRITE MODES = 24  
 TOTAL NO. MODES = 83

CONDUCTOR ENDPOINT COORDINATES :  
 N = POINT NO.      X(N)      Y(N)

|    |        |        |
|----|--------|--------|
| 1  | 0.0000 | 0.0000 |
| 2  | 0.0000 | 0.0833 |
| 3  | 0.0000 | 0.1667 |
| 4  | 0.0000 | 0.2500 |
| 5  | 0.0000 | 0.3333 |
| 6  | 0.0000 | 0.4167 |
| 7  | 0.0000 | 0.5000 |
| 8  | 0.0833 | 0.0000 |
| 9  | 0.1667 | 0.0000 |
| 10 | 0.2500 | 0.0000 |
| 11 | 0.3333 | 0.0000 |
| 12 | 0.4167 | 0.0000 |

13                    0.5000           0.0000

CONDUCTOR MODE STRIP SEGMENTS:

| I  | IA(I) | IB(I) | D(I)  | ZSH1(I)         | ZSH2(I)          |
|----|-------|-------|-------|-----------------|------------------|
| 1  | 1     | 2     | 0.083 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 2  | 2     | 3     | 0.083 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 3  | 3     | 4     | 0.083 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 4  | 4     | 5     | 0.083 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 5  | 5     | 6     | 0.083 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 6  | 6     | 7     | 0.083 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 7  | 1     | 8     | 0.083 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 8  | 8     | 9     | 0.083 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 9  | 9     | 10    | 0.083 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 10 | 10    | 11    | 0.083 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 11 | 11    | 12    | 0.083 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 12 | 12    | 13    | 0.083 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |

CONDUCTOR MODE NUMBERS:

| I = MODE | I1(I) | I2(I) | I3(I) |
|----------|-------|-------|-------|
| 1        | 2     | 1     | 8     |
| 2        | 1     | 2     | 3     |
| 3        | 2     | 3     | 4     |
| 4        | 3     | 4     | 5     |
| 5        | 4     | 5     | 6     |
| 6        | 5     | 6     | 7     |
| 7        | 1     | 8     | 9     |
| 8        | 8     | 9     | 10    |
| 9        | 9     | 10    | 11    |
| 10       | 10    | 11    | 12    |
| 11       | 11    | 12    | 13    |

MATERIAL CELL ENDPOINT COORDINATES :

| CELL | XD1   | YD1   | XD2   | YD2   | XD3   | YD3   | XD4   | YD4   |
|------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1    | 0.000 | 0.000 | 0.000 | 0.083 | 0.050 | 0.125 | 0.050 | 0.050 |
| 2    | 0.000 | 0.083 | 0.000 | 0.167 | 0.050 | 0.200 | 0.050 | 0.125 |
| 3    | 0.000 | 0.167 | 0.000 | 0.250 | 0.050 | 0.275 | 0.050 | 0.200 |
| 4    | 0.000 | 0.250 | 0.000 | 0.333 | 0.050 | 0.350 | 0.050 | 0.275 |
| 5    | 0.000 | 0.333 | 0.000 | 0.417 | 0.050 | 0.425 | 0.050 | 0.350 |
| 6    | 0.000 | 0.417 | 0.000 | 0.500 | 0.050 | 0.500 | 0.050 | 0.425 |
| 7    | 0.050 | 0.050 | 0.050 | 0.125 | 0.100 | 0.167 | 0.100 | 0.100 |
| 8    | 0.050 | 0.125 | 0.050 | 0.200 | 0.100 | 0.233 | 0.100 | 0.167 |

|    |       |       |       |       |       |       |       |       |
|----|-------|-------|-------|-------|-------|-------|-------|-------|
| 9  | 0.050 | 0.200 | 0.050 | 0.275 | 0.100 | 0.300 | 0.100 | 0.233 |
| 10 | 0.050 | 0.275 | 0.050 | 0.350 | 0.100 | 0.367 | 0.100 | 0.300 |
| 11 | 0.050 | 0.350 | 0.050 | 0.425 | 0.100 | 0.433 | 0.100 | 0.367 |
| 12 | 0.050 | 0.425 | 0.050 | 0.500 | 0.100 | 0.500 | 0.100 | 0.433 |
| 13 | 0.000 | 0.000 | 0.083 | 0.000 | 0.125 | 0.050 | 0.050 | 0.050 |
| 14 | 0.083 | 0.000 | 0.167 | 0.000 | 0.200 | 0.050 | 0.125 | 0.050 |
| 15 | 0.167 | 0.000 | 0.250 | 0.000 | 0.275 | 0.050 | 0.200 | 0.050 |
| 16 | 0.250 | 0.000 | 0.333 | 0.000 | 0.350 | 0.050 | 0.275 | 0.050 |
| 17 | 0.333 | 0.000 | 0.417 | 0.000 | 0.425 | 0.050 | 0.350 | 0.050 |
| 18 | 0.417 | 0.000 | 0.500 | 0.000 | 0.500 | 0.050 | 0.425 | 0.050 |
| 19 | 0.050 | 0.050 | 0.125 | 0.050 | 0.167 | 0.100 | 0.100 | 0.100 |
| 20 | 0.125 | 0.050 | 0.200 | 0.050 | 0.233 | 0.100 | 0.167 | 0.100 |
| 21 | 0.200 | 0.050 | 0.275 | 0.050 | 0.300 | 0.100 | 0.233 | 0.100 |
| 22 | 0.275 | 0.050 | 0.350 | 0.050 | 0.367 | 0.100 | 0.300 | 0.100 |
| 23 | 0.350 | 0.050 | 0.425 | 0.050 | 0.433 | 0.100 | 0.367 | 0.100 |
| 24 | 0.425 | 0.050 | 0.500 | 0.050 | 0.500 | 0.100 | 0.433 | 0.100 |

# RHS OR VOLTAGE VECTOR

| I  | V-MAG     | PHASE(DEG) |
|----|-----------|------------|
| 1  | 22.649950 | 7.13       |
| 2  | 22.474653 | -158.79    |
| 3  | 22.474655 | -137.57    |
| 4  | 22.474655 | -116.36    |
| 5  | 22.474651 | -95.15     |
| 6  | 22.474665 | -73.93     |
| 7  | 22.474651 | 21.21      |
| 8  | 22.474659 | 42.43      |
| 9  | 22.474651 | 63.64      |
| 10 | 22.474651 | 84.85      |
| 11 | 22.474653 | 106.07     |
| 12 | 1.000000  | 22.80      |
| 13 | 1.000000  | 42.96      |
| 14 | 1.000000  | 63.11      |
| 15 | 1.000000  | 83.26      |
| 16 | 1.000000  | 103.41     |
| 17 | 1.000000  | 123.57     |
| 18 | 1.000000  | 47.20      |
| 19 | 1.000000  | 65.23      |
| 20 | 1.000000  | 83.26      |
| 21 | 1.000000  | 101.29     |
| 22 | 1.000000  | 119.32     |
| 23 | 1.000000  | 137.36     |
| 24 | 1.000000  | 22.80      |

|    |            |         |
|----|------------|---------|
| 25 | 1.000000   | 42.96   |
| 26 | 1.000000   | 63.11   |
| 27 | 1.000000   | 83.26   |
| 28 | 1.000000   | 103.41  |
| 29 | 1.000000   | 123.57  |
| 30 | 1.000000   | 47.20   |
| 31 | 1.000000   | 65.23   |
| 32 | 1.000000   | 83.26   |
| 33 | 1.000000   | 101.29  |
| 34 | 1.000000   | 119.32  |
| 35 | 1.000000   | 137.36  |
| 36 | 16.375847  | 22.80   |
| 37 | 53.315880  | 42.96   |
| 38 | 95.944054  | 63.11   |
| 39 | 143.542801 | 83.26   |
| 40 | 193.965149 | 103.41  |
| 41 | 243.520264 | 123.57  |
| 42 | 16.375803  | 47.20   |
| 43 | 53.315742  | 65.23   |
| 44 | 95.943878  | 83.26   |
| 45 | 143.542603 | 101.29  |
| 46 | 193.964767 | 119.32  |
| 47 | 243.520096 | 137.36  |
| 48 | 16.375847  | -157.20 |
| 49 | 53.315880  | -137.04 |
| 50 | 95.944054  | -116.89 |
| 51 | 143.542801 | -96.74  |
| 52 | 193.965149 | -76.59  |
| 53 | 243.520264 | -56.43  |
| 54 | 16.375803  | -132.80 |
| 55 | 53.315742  | -114.77 |
| 56 | 95.943878  | -96.74  |
| 57 | 143.542603 | -78.71  |
| 58 | 193.964767 | -60.68  |
| 59 | 243.520096 | -42.64  |
| 60 | 266.579254 | -157.20 |
| 61 | 266.579254 | -137.04 |
| 62 | 266.579254 | -116.89 |
| 63 | 266.579254 | -96.74  |
| 64 | 266.579254 | -76.59  |
| 65 | 266.579254 | -56.43  |
| 66 | 266.579254 | -132.80 |
| 67 | 266.579254 | -114.77 |
| 68 | 266.579254 | -96.74  |



|    |            |        |
|----|------------|--------|
| 69 | 266.579224 | -78.71 |
| 70 | 266.579224 | -60.68 |
| 71 | 266.579285 | -42.64 |
| 72 | 266.579254 | 22.80  |
| 73 | 266.579254 | 42.96  |
| 74 | 266.579254 | 63.11  |
| 75 | 266.579254 | 83.26  |
| 76 | 266.579254 | 103.41 |
| 77 | 266.579254 | 123.57 |
| 78 | 266.579254 | 47.20  |
| 79 | 266.579254 | 65.23  |
| 80 | 266.579254 | 83.26  |
| 81 | 266.579224 | 101.29 |
| 82 | 266.579224 | 119.32 |
| 83 | 266.579285 | 137.36 |

# CURRENT OR SOLUTION VECTOR

| M  | I-MAG    | PHASE(DEG) |
|----|----------|------------|
| 1  | 4.770626 | 6.62       |
| 2  | 4.082648 | -174.77    |
| 3  | 2.446153 | -176.98    |
| 4  | 0.524794 | 165.98     |
| 5  | 1.120826 | 17.35      |
| 6  | 1.755641 | 14.77      |
| 7  | 4.082999 | 5.23       |
| 8  | 2.445320 | 3.02       |
| 9  | 0.524887 | -14.02     |
| 10 | 1.120720 | -162.65    |
| 11 | 1.755550 | -165.23    |
| 12 | 0.000432 | 87.94      |
| 13 | 0.000326 | 88.71      |
| 14 | 0.000168 | 92.56      |
| 15 | 0.000026 | 176.16     |
| 16 | 0.000130 | -109.64    |
| 17 | 0.000155 | -114.04    |
| 18 | 0.000285 | 89.17      |
| 19 | 0.000193 | 90.33      |
| 20 | 0.000080 | 96.50      |
| 21 | 0.000037 | -119.41    |
| 22 | 0.000118 | -103.50    |
| 23 | 0.000144 | -104.40    |
| 24 | 0.000432 | 87.94      |
| 25 | 0.000326 | 88.71      |

|    |          |         |
|----|----------|---------|
| 26 | 0.000168 | 92.56   |
| 27 | 0.000026 | 176.15  |
| 28 | 0.000130 | -109.64 |
| 29 | 0.000155 | -114.04 |
| 30 | 0.000285 | 89.17   |
| 31 | 0.000193 | 90.33   |
| 32 | 0.000080 | 96.50   |
| 33 | 0.000037 | -119.41 |
| 34 | 0.000118 | -103.50 |
| 35 | 0.000144 | -104.40 |
| 36 | 0.018956 | 173.81  |
| 37 | 0.050330 | 172.60  |
| 38 | 0.066084 | 172.06  |
| 39 | 0.061204 | 171.17  |
| 40 | 0.034657 | 168.03  |
| 41 | 0.024388 | 20.34   |
| 42 | 0.011347 | 171.00  |
| 43 | 0.030743 | 171.14  |
| 44 | 0.042148 | 170.76  |
| 45 | 0.040444 | 169.85  |
| 46 | 0.024730 | 166.79  |
| 47 | 0.004968 | 43.50   |
| 48 | 0.018950 | -6.20   |
| 49 | 0.050353 | -7.39   |
| 50 | 0.066068 | -7.95   |
| 51 | 0.061202 | -8.83   |
| 52 | 0.034657 | -11.97  |
| 53 | 0.024386 | -159.66 |
| 54 | 0.011348 | -9.00   |
| 55 | 0.030749 | -8.86   |
| 56 | 0.042144 | -9.24   |
| 57 | 0.040443 | -10.15  |
| 58 | 0.024730 | -13.21  |
| 59 | 0.004968 | -136.49 |
| 60 | 0.022231 | -10.26  |
| 61 | 0.023491 | -9.36   |
| 62 | 0.017623 | -6.52   |
| 63 | 0.008627 | 6.08    |
| 64 | 0.003633 | 77.73   |
| 65 | 0.017044 | 34.16   |
| 66 | 0.060393 | -9.94   |
| 67 | 0.053673 | -8.51   |
| 68 | 0.036524 | -4.06   |
| 69 | 0.016693 | 14.19   |

|    |          |         |
|----|----------|---------|
| 70 | 0.010137 | 83.42   |
| 71 | 0.014583 | 74.51   |
| 72 | 0.022238 | 169.75  |
| 73 | 0.023484 | 170.64  |
| 74 | 0.017617 | 173.48  |
| 75 | 0.008630 | -173.92 |
| 76 | 0.003633 | -102.29 |
| 77 | 0.017044 | -145.84 |
| 78 | 0.060394 | 170.06  |
| 79 | 0.053668 | 171.49  |
| 80 | 0.036522 | 175.94  |
| 81 | 0.016694 | -165.81 |
| 82 | 0.010137 | -96.59  |
| 83 | 0.014583 | -105.49 |

BISTATIC PATTERN: PHI INCIDENT (DEG) = 45.00

PHI S(DEG) ECHO WIDTH(M) ECHO WIDTH(DB/M) |FIELD| PHASE(DEG)

|        |        |         |       |        |
|--------|--------|---------|-------|--------|
| 0.00   | 0.5388 | -2.6860 | 0.293 | 4.27   |
| 5.00   | 0.6216 | -2.0647 | 0.315 | 10.23  |
| 10.00  | 0.7188 | -1.4340 | 0.338 | 15.50  |
| 15.00  | 0.8270 | -0.8249 | 0.363 | 20.07  |
| 20.00  | 0.9408 | -0.2650 | 0.387 | 23.97  |
| 25.00  | 1.0526 | 0.2228  | 0.409 | 27.18  |
| 30.00  | 1.1535 | 0.6201  | 0.428 | 29.69  |
| 35.00  | 1.2340 | 0.9132  | 0.443 | 31.49  |
| 40.00  | 1.2861 | 1.0927  | 0.452 | 32.57  |
| 45.00  | 1.3041 | 1.1532  | 0.456 | 32.94  |
| 50.00  | 1.2861 | 1.0927  | 0.452 | 32.57  |
| 55.00  | 1.2340 | 0.9132  | 0.443 | 31.49  |
| 60.00  | 1.1535 | 0.6200  | 0.428 | 29.69  |
| 65.00  | 1.0526 | 0.2227  | 0.409 | 27.18  |
| 70.00  | 0.9408 | -0.2650 | 0.387 | 23.97  |
| 75.00  | 0.8270 | -0.8250 | 0.363 | 20.07  |
| 80.00  | 0.7188 | -1.4341 | 0.338 | 15.50  |
| 85.00  | 0.6216 | -2.0648 | 0.315 | 10.23  |
| 90.00  | 0.5388 | -2.6861 | 0.293 | 4.27   |
| 95.00  | 0.4715 | -3.2652 | 0.274 | -2.39  |
| 100.00 | 0.4197 | -3.7706 | 0.258 | -9.74  |
| 105.00 | 0.3823 | -4.1761 | 0.247 | -17.74 |
| 110.00 | 0.3577 | -4.4644 | 0.239 | -26.30 |
| 115.00 | 0.3443 | -4.6303 | 0.234 | -35.29 |
| 120.00 | 0.3403 | -4.6817 | 0.233 | -44.55 |
| 125.00 | 0.3437 | -4.6378 | 0.234 | -53.86 |

|        |        |         |       |         |
|--------|--------|---------|-------|---------|
| 130.00 | 0.3528 | -4.5251 | 0.237 | -63.04  |
| 135.00 | 0.3653 | -4.3729 | 0.241 | -71.87  |
| 140.00 | 0.3794 | -4.2088 | 0.246 | -80.18  |
| 145.00 | 0.3931 | -4.0548 | 0.250 | -87.79  |
| 150.00 | 0.4051 | -3.9244 | 0.254 | -94.51  |
| 155.00 | 0.4149 | -3.8202 | 0.257 | -100.16 |
| 160.00 | 0.4235 | -3.7318 | 0.260 | -104.58 |
| 165.00 | 0.4331 | -3.6336 | 0.263 | -107.64 |
| 170.00 | 0.4480 | -3.4872 | 0.267 | -109.31 |
| 175.00 | 0.4733 | -3.2486 | 0.274 | -109.73 |
| 180.00 | 0.5147 | -2.8841 | 0.286 | -109.20 |
| 185.00 | 0.5772 | -2.3865 | 0.303 | -108.15 |
| 190.00 | 0.6635 | -1.7818 | 0.325 | -106.99 |
| 195.00 | 0.7725 | -1.1212 | 0.351 | -106.02 |
| 200.00 | 0.8987 | -0.4638 | 0.378 | -105.38 |
| 205.00 | 1.0321 | 0.1370  | 0.405 | -105.04 |
| 210.00 | 1.1588 | 0.6402  | 0.429 | -104.93 |
| 215.00 | 1.2639 | 1.0170  | 0.448 | -104.94 |
| 220.00 | 1.3334 | 1.2496  | 0.461 | -104.98 |
| 225.00 | 1.3577 | 1.3281  | 0.465 | -105.01 |
| 230.00 | 1.3334 | 1.2496  | 0.461 | -104.98 |
| 235.00 | 1.2639 | 1.0170  | 0.448 | -104.94 |
| 240.00 | 1.1588 | 0.6402  | 0.429 | -104.93 |
| 245.00 | 1.0321 | 0.1370  | 0.405 | -105.04 |
| 250.00 | 0.8987 | -0.4638 | 0.378 | -105.38 |
| 255.00 | 0.7725 | -1.1212 | 0.351 | -106.02 |
| 260.00 | 0.6635 | -1.7818 | 0.325 | -106.99 |
| 265.00 | 0.5772 | -2.3865 | 0.303 | -108.15 |
| 270.00 | 0.5147 | -2.8842 | 0.286 | -109.20 |
| 275.00 | 0.4733 | -3.2487 | 0.274 | -109.73 |
| 280.00 | 0.4480 | -3.4873 | 0.267 | -109.31 |
| 285.00 | 0.4331 | -3.6337 | 0.263 | -107.64 |
| 290.00 | 0.4235 | -3.7319 | 0.260 | -104.58 |
| 295.00 | 0.4149 | -3.8204 | 0.257 | -100.16 |
| 300.00 | 0.4051 | -3.9245 | 0.254 | -94.51  |
| 305.00 | 0.3931 | -4.0549 | 0.250 | -87.79  |
| 310.00 | 0.3794 | -4.2090 | 0.246 | -80.18  |
| 315.00 | 0.3653 | -4.3730 | 0.241 | -71.87  |
| 320.00 | 0.3528 | -4.5252 | 0.237 | -63.03  |
| 325.00 | 0.3437 | -4.6378 | 0.234 | -53.86  |
| 330.00 | 0.3403 | -4.6817 | 0.233 | -44.54  |
| 335.00 | 0.3443 | -4.6303 | 0.234 | -35.29  |
| 340.00 | 0.3577 | -4.4643 | 0.239 | -26.30  |
| 345.00 | 0.3823 | -4.1760 | 0.247 | -17.74  |

|        |        |         |       |       |
|--------|--------|---------|-------|-------|
| 350.00 | 0.4197 | -3.7705 | 0.258 | -9.74 |
| 355.00 | 0.4715 | -3.2651 | 0.274 | -2.39 |
| 360.00 | 0.5388 | -2.6860 | 0.293 | 4.27  |

TOTAL CPU TIME= 94.66 SEC

# Appendix H

## Output for Example 5

```
*****THE OHIO STATE UNIVERSITY*****  
PLANE WAVE SCATTERING BY A GENERAL CYLINDER  
*****EXAMPLE 5*****
```

```
COMMAND PRC: PRINT COMMANDS
```

```
**** LISTING OF COMMANDS AND INPUTS ****
```

```
COMMAND MDG: MODE GEOMETRY
```

```
COMMAND SUB: SUBROUTINE GENERATED GEOMETRY  
IRDG = 0
```

```
COMMAND ACU: ACCURACY PARAMETERS  
INTM =16   INT = 6   SEGM =.150   SEGC =.150
```

```
COMMAND FMZ: FREQUENCY  
FMHZ =   300.0000
```

```
COMMAND WRI: WRITE INDICATORS  
IZWR = 0   ICWR = 0
```

```
COMMAND POL: POLARIZATION TYPE  
NPOL =1
```

```
COMMAND SCP: SCATTERING PATTERN
```

IPAT = 1 PHID = 0.00 STEP = 5.00

COMMAND END: END OF INPUT DATA

SUMMARY OF RUN CONTROL PARAMETERS:

NGO; PARAMETER TO CONTINUE RUN = 1  
NPOL; INDICATOR FOR POLARIZATION TYPE = 1  
IPAT; INDICATOR FOR PATTERN TYPE = 1  
PHID; DIRECTION OF INCIDENT WAVE IN DEG. = 0.0  
STEP; INCREMENT OF PATTERN ANGLE IN DEG. = 5.0  
INF; INDICATOR FOR INTERNAL FIELDS = 0  
INT; CONDUCTOR INTEGRATION SEGMENTATIONS = 6  
INTM; MATERIAL SELF-ELEMENT INTEGRATION SEGMENTATIONS = 16  
IZWR; INDICATOR TO WRITE Z-MATRIX = 0  
ICWR; INDICATOR TO WRITE CURRENTS AND RHS VECTOR = 0  
IRDG; INDICATOR FOR INPUT TYPE = 0  
IDIE; INDICATOR FOR DIELECTRIC = 1  
IFER; INDICATOR FOR FERRITE = 1  
FHMZ; FREQUENCY IN MHZ = 300.0000  
WV; WAVELENGTH IN METERS = 1.0000  
SEGM; MAXIMUM SEGMENT SIZE IN MAT. WV = 0.150  
SEGC; MAXIMUM SEGMENT SIZE OF CONDUCTOR MODES = 0.150  
IMODE; INDICATOR TO PRINT MODE INFORMATION = 1

GEOMETRY FOR THE 24 BUILDING BLOCKS:  
(LINEAR DIMENSIONS IN METERS)

GEOMETRY FOR BUILDING BLOCK 1

BLOCK TYPE = 3

| PT. | X      | Y      |
|-----|--------|--------|
| 1   | 0.1509 | 0.0000 |
| 2   | 0.1457 | 0.0390 |
| 3   | 0.2429 | 0.0651 |
| 4   | 0.2514 | 0.0000 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)  
ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00  
NO. OF MATERIAL CELLS = 2  
NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 2

BLOCK TYPE = 3

| PT. | X      | Y      |
|-----|--------|--------|
| 1   | 0.1457 | 0.0390 |
| 2   | 0.1306 | 0.0754 |
| 3   | 0.2177 | 0.1257 |
| 4   | 0.2429 | 0.0651 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
 IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
 ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)  
 ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00  
 NO. OF MATERIAL CELLS = 2  
 NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 3

BLOCK TYPE = 3

| PT. | X      | Y      |
|-----|--------|--------|
| 1   | 0.1306 | 0.0754 |
| 2   | 0.1067 | 0.1067 |
| 3   | 0.1778 | 0.1778 |
| 4   | 0.2177 | 0.1257 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
 IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
 ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)  
 ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00  
 NO. OF MATERIAL CELLS = 2  
 NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 4

BLOCK TYPE = 3

| PT. | X      | Y      |
|-----|--------|--------|
| 1   | 0.1067 | 0.1067 |
| 2   | 0.0754 | 0.1306 |
| 3   | 0.1257 | 0.2177 |
| 4   | 0.1778 | 0.1778 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
 IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
 ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)  
 ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00  
 NO. OF MATERIAL CELLS = 2  
 NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 5

BLOCK TYPE = 3

| PT. | X      | Y      |
|-----|--------|--------|
| 1   | 0.0754 | 0.1306 |



|   |        |        |
|---|--------|--------|
| 2 | 0.0390 | 0.1457 |
| 3 | 0.0651 | 0.2429 |
| 4 | 0.1257 | 0.2177 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
 IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
 ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)  
 ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00  
 NO. OF MATERIAL CELLS = 2  
 NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 6  
 BLOCK TYPE = 3

|     |        |        |
|-----|--------|--------|
| PT. | X      | Y      |
| 1   | 0.0390 | 0.1457 |
| 2   | 0.0000 | 0.1509 |
| 3   | 0.0000 | 0.2514 |
| 4   | 0.0651 | 0.2429 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
 IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
 ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)  
 ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00  
 NO. OF MATERIAL CELLS = 2  
 NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 7  
 BLOCK TYPE = 3

|     |         |        |
|-----|---------|--------|
| PT. | X       | Y      |
| 1   | 0.0000  | 0.1509 |
| 2   | -0.0390 | 0.1457 |
| 3   | -0.0651 | 0.2429 |
| 4   | 0.0000  | 0.2514 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
 IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
 ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)  
 ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00  
 NO. OF MATERIAL CELLS = 2  
 NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 8  
 BLOCK TYPE = 3

|     |         |        |
|-----|---------|--------|
| PT. | X       | Y      |
| 1   | -0.0390 | 0.1457 |
| 2   | -0.0754 | 0.1306 |
| 3   | -0.1257 | 0.2177 |

4     -0.0651     0.2429  
 REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
 IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
 ZSHT1 = (.00E+00, .00E+00)   ZSHT2 = (.00E+00, .00E+00)  
 ER = 3.000   TDE = .0E+00   UR = 1.500   TDM = .1E+00  
 NO. OF MATERIAL CELLS = 2  
 NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 9  
 BLOCK TYPE = 3

| PT. | X       | Y      |
|-----|---------|--------|
| 1   | -0.0754 | 0.1306 |
| 2   | -0.1067 | 0.1067 |
| 3   | -0.1778 | 0.1778 |
| 4   | -0.1257 | 0.2177 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
 IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
 ZSHT1 = (.00E+00, .00E+00)   ZSHT2 = (.00E+00, .00E+00)  
 ER = 3.000   TDE = .0E+00   UR = 1.500   TDM = .1E+00  
 NO. OF MATERIAL CELLS = 2  
 NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 10  
 BLOCK TYPE = 3

| PT. | X       | Y      |
|-----|---------|--------|
| 1   | -0.1067 | 0.1067 |
| 2   | -0.1306 | 0.0754 |
| 3   | -0.2177 | 0.1257 |
| 4   | -0.1778 | 0.1778 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
 IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
 ZSHT1 = (.00E+00, .00E+00)   ZSHT2 = (.00E+00, .00E+00)  
 ER = 3.000   TDE = .0E+00   UR = 1.500   TDM = .1E+00  
 NO. OF MATERIAL CELLS = 2  
 NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 11  
 BLOCK TYPE = 3

| PT. | X       | Y      |
|-----|---------|--------|
| 1   | -0.1306 | 0.0754 |
| 2   | -0.1457 | 0.0390 |
| 3   | -0.2429 | 0.0651 |
| 4   | -0.2177 | 0.1257 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1

IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
 ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)  
 ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00  
 NO. OF MATERIAL CELLS = 2  
 NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 12  
 BLOCK TYPE = 3

| PT. | X       | Y      |
|-----|---------|--------|
| 1   | -0.1457 | 0.0390 |
| 2   | -0.1509 | 0.0000 |
| 3   | -0.2514 | 0.0000 |
| 4   | -0.2429 | 0.0651 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
 IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
 ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)  
 ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00  
 NO. OF MATERIAL CELLS = 2  
 NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 13  
 BLOCK TYPE = 3

| PT. | X       | Y       |
|-----|---------|---------|
| 1   | -0.1509 | 0.0000  |
| 2   | -0.1457 | -0.0390 |
| 3   | -0.2429 | -0.0651 |
| 4   | -0.2514 | 0.0000  |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
 IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
 ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)  
 ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00  
 NO. OF MATERIAL CELLS = 2  
 NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 14  
 BLOCK TYPE = 3

| PT. | X       | Y       |
|-----|---------|---------|
| 1   | -0.1457 | -0.0390 |
| 2   | -0.1306 | -0.0754 |
| 3   | -0.2177 | -0.1257 |
| 4   | -0.2429 | -0.0651 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
 IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
 ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)

ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00  
NO. OF MATERIAL CELLS = 2  
NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 15

BLOCK TYPE = 3

| PT. | X       | Y       |
|-----|---------|---------|
| 1   | -0.1306 | -0.0754 |
| 2   | -0.1067 | -0.1067 |
| 3   | -0.1778 | -0.1778 |
| 4   | -0.2177 | -0.1257 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1

IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1

ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)

ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00

NO. OF MATERIAL CELLS = 2

NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 16

BLOCK TYPE = 3

| PT. | X       | Y       |
|-----|---------|---------|
| 1   | -0.1067 | -0.1067 |
| 2   | -0.0754 | -0.1306 |
| 3   | -0.1257 | -0.2177 |
| 4   | -0.1778 | -0.1778 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1

IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1

ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)

ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00

NO. OF MATERIAL CELLS = 2

NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 17

BLOCK TYPE = 3

| PT. | X       | Y       |
|-----|---------|---------|
| 1   | -0.0754 | -0.1306 |
| 2   | -0.0390 | -0.1457 |
| 3   | -0.0651 | -0.2429 |
| 4   | -0.1257 | -0.2177 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1

IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1

ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)

ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00

NO. OF MATERIAL CELLS = 2

NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 18

BLOCK TYPE = 3

| PT. | X       | Y       |
|-----|---------|---------|
| 1   | -0.0390 | -0.1457 |
| 2   | 0.0000  | -0.1509 |
| 3   | 0.0000  | -0.2514 |
| 4   | -0.0651 | -0.2429 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1

IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1

ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)

ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00

NO. OF MATERIAL CELLS = 2

NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 19

BLOCK TYPE = 3

| PT. | X      | Y       |
|-----|--------|---------|
| 1   | 0.0000 | -0.1509 |
| 2   | 0.0390 | -0.1457 |
| 3   | 0.0651 | -0.2429 |
| 4   | 0.0000 | -0.2514 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1

IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1

ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)

ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00

NO. OF MATERIAL CELLS = 2

NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 20

BLOCK TYPE = 3

| PT. | X      | Y       |
|-----|--------|---------|
| 1   | 0.0390 | -0.1457 |
| 2   | 0.0754 | -0.1306 |
| 3   | 0.1257 | -0.2177 |
| 4   | 0.0651 | -0.2429 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1

IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1

ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)

ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00

NO. OF MATERIAL CELLS = 2

NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 21

BLOCK TYPE = 3

| PT. | X      | Y       |
|-----|--------|---------|
| 1   | 0.0754 | -0.1306 |
| 2   | 0.1067 | -0.1067 |
| 3   | 0.1778 | -0.1778 |
| 4   | 0.1257 | -0.2177 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1

IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1

ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)

ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00

NO. OF MATERIAL CELLS = 2

NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 22

BLOCK TYPE = 3

| PT. | X      | Y       |
|-----|--------|---------|
| 1   | 0.1067 | -0.1067 |
| 2   | 0.1306 | -0.0754 |
| 3   | 0.2177 | -0.1257 |
| 4   | 0.1778 | -0.1778 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1

IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1

ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)

ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00

NO. OF MATERIAL CELLS = 2

NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 23

BLOCK TYPE = 3

| PT. | X      | Y       |
|-----|--------|---------|
| 1   | 0.1306 | -0.0754 |
| 2   | 0.1457 | -0.0390 |
| 3   | 0.2429 | -0.0651 |
| 4   | 0.2177 | -0.1257 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1

IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1

ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)

ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00

NO. OF MATERIAL CELLS = 2

NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 24

BLOCK TYPE = 3

| PT. | X      | Y       |
|-----|--------|---------|
| 1   | 0.1457 | -0.0390 |
| 2   | 0.1509 | 0.0000  |
| 3   | 0.2514 | 0.0000  |
| 4   | 0.2429 | -0.0651 |

REAL PART SHEET IMPEDANCE TAPER TYPE = 1  
 IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1  
 ZSHT1 = (.00E+00, .00E+00) ZSHT2 = (.00E+00, .00E+00)  
 ER = 3.000 TDE = .0E+00 UR = 1.500 TDM = .1E+00  
 NO. OF MATERIAL CELLS = 2  
 NO. SHEET IMPEDANCE SEGMENTS = 1

SUMMARY OF MODES:

|  |     |
|--|-----|
| NO. SHEET IMPEDANCE OR CONDUCTOR MODES = | 24  |
| NO. DIELECTRIC MODES =                   | 96  |
| NO. FERRITE MODES =                      | 48  |
| TOTAL NO. MODES =                        | 168 |

CONDUCTOR ENDPOINT COORDINATES :

| N = POINT NO. | X(N) | Y(N) |
|---------------|------|------|
|---------------|------|------|

|    |         |         |
|----|---------|---------|
| 1  | 0.1509  | 0.0000  |
| 2  | 0.1457  | 0.0390  |
| 3  | 0.1306  | 0.0754  |
| 4  | 0.1067  | 0.1067  |
| 5  | 0.0754  | 0.1306  |
| 6  | 0.0390  | 0.1457  |
| 7  | 0.0000  | 0.1509  |
| 8  | -0.0390 | 0.1457  |
| 9  | -0.0754 | 0.1306  |
| 10 | -0.1067 | 0.1067  |
| 11 | -0.1306 | 0.0754  |
| 12 | -0.1457 | 0.0390  |
| 13 | -0.1509 | 0.0000  |
| 14 | -0.1457 | -0.0390 |
| 15 | -0.1306 | -0.0754 |
| 16 | -0.1067 | -0.1067 |
| 17 | -0.0754 | -0.1306 |
| 18 | -0.0390 | -0.1457 |
| 19 | 0.0000  | -0.1509 |
| 20 | 0.0390  | -0.1457 |
| 21 | 0.0754  | -0.1306 |
| 22 | 0.1067  | -0.1067 |
| 23 | 0.1306  | -0.0754 |

24

0.1457      -0.0390

## CONDUCTOR MODE STRIP SEGMENTS:

| I  | IA(I) | IB(I) | D(I)  | ZSH1(I)         | ZSH2(I)          |
|----|-------|-------|-------|-----------------|------------------|
| 1  | 1     | 2     | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 2  | 2     | 3     | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 3  | 3     | 4     | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 4  | 4     | 5     | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 5  | 5     | 6     | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 6  | 6     | 7     | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 7  | 7     | 8     | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 8  | 8     | 9     | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 9  | 9     | 10    | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 10 | 10    | 11    | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 11 | 11    | 12    | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 12 | 12    | 13    | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 13 | 13    | 14    | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 14 | 14    | 15    | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 15 | 15    | 16    | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 16 | 16    | 17    | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 17 | 17    | 18    | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 18 | 18    | 19    | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 19 | 19    | 20    | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 20 | 20    | 21    | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 21 | 21    | 22    | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 22 | 22    | 23    | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 23 | 23    | 24    | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |
| 24 | 24    | 1     | 0.039 | (.0E+00,.0E+00) | (.0E+00, .0E+00) |

## CONDUCTOR MODE NUMBERS:

| I = MODE | I1(I) | I2(I) | I3(I) |
|----------|-------|-------|-------|
| 1        | 2     | 1     | 24    |
| 2        | 1     | 2     | 3     |
| 3        | 2     | 3     | 4     |
| 4        | 3     | 4     | 5     |
| 5        | 4     | 5     | 6     |
| 6        | 5     | 6     | 7     |
| 7        | 6     | 7     | 8     |
| 8        | 7     | 8     | 9     |
| 9        | 8     | 9     | 10    |
| 10       | 9     | 10    | 11    |
| 11       | 10    | 11    | 12    |



|    |    |    |    |
|----|----|----|----|
| 12 | 11 | 12 | 13 |
| 13 | 12 | 13 | 14 |
| 14 | 13 | 14 | 15 |
| 15 | 14 | 15 | 16 |
| 16 | 15 | 16 | 17 |
| 17 | 16 | 17 | 18 |
| 18 | 17 | 18 | 19 |
| 19 | 18 | 19 | 20 |
| 20 | 19 | 20 | 21 |
| 21 | 20 | 21 | 22 |
| 22 | 21 | 22 | 23 |
| 23 | 22 | 23 | 24 |
| 24 | 23 | 24 | 1  |

MATERIAL CELL ENDPOINT COORDINATES :

| CELL | XD1    | YD1    | XD2    | YD2    | XD3    | YD3    | XD4    | YD4    |
|------|--------|--------|--------|--------|--------|--------|--------|--------|
| 1    | 0.151  | 0.000  | 0.146  | 0.039  | 0.194  | 0.052  | 0.201  | 0.000  |
| 2    | 0.201  | 0.000  | 0.194  | 0.052  | 0.243  | 0.065  | 0.251  | 0.000  |
| 3    | 0.146  | 0.039  | 0.131  | 0.075  | 0.174  | 0.101  | 0.194  | 0.052  |
| 4    | 0.194  | 0.052  | 0.174  | 0.101  | 0.218  | 0.126  | 0.243  | 0.065  |
| 5    | 0.131  | 0.075  | 0.107  | 0.107  | 0.142  | 0.142  | 0.174  | 0.101  |
| 6    | 0.174  | 0.101  | 0.142  | 0.142  | 0.178  | 0.178  | 0.218  | 0.126  |
| 7    | 0.107  | 0.107  | 0.075  | 0.131  | 0.101  | 0.174  | 0.142  | 0.142  |
| 8    | 0.142  | 0.142  | 0.101  | 0.174  | 0.126  | 0.218  | 0.178  | 0.178  |
| 9    | 0.075  | 0.131  | 0.039  | 0.146  | 0.052  | 0.194  | 0.101  | 0.174  |
| 10   | 0.101  | 0.174  | 0.052  | 0.194  | 0.065  | 0.243  | 0.126  | 0.218  |
| 11   | 0.039  | 0.146  | 0.000  | 0.151  | 0.000  | 0.201  | 0.052  | 0.194  |
| 12   | 0.052  | 0.194  | 0.000  | 0.201  | 0.000  | 0.251  | 0.065  | 0.243  |
| 13   | 0.000  | 0.151  | -0.039 | 0.146  | -0.052 | 0.194  | 0.000  | 0.201  |
| 14   | 0.000  | 0.201  | -0.052 | 0.194  | -0.065 | 0.243  | 0.000  | 0.251  |
| 15   | -0.039 | 0.146  | -0.075 | 0.131  | -0.101 | 0.174  | -0.052 | 0.194  |
| 16   | -0.052 | 0.194  | -0.101 | 0.174  | -0.126 | 0.218  | -0.065 | 0.243  |
| 17   | -0.075 | 0.131  | -0.107 | 0.107  | -0.142 | 0.142  | -0.101 | 0.174  |
| 18   | -0.101 | 0.174  | -0.142 | 0.142  | -0.178 | 0.178  | -0.126 | 0.218  |
| 19   | -0.107 | 0.107  | -0.131 | 0.075  | -0.174 | 0.101  | -0.142 | 0.142  |
| 20   | -0.142 | 0.142  | -0.174 | 0.101  | -0.218 | 0.126  | -0.178 | 0.178  |
| 21   | -0.131 | 0.075  | -0.146 | 0.039  | -0.194 | 0.052  | -0.174 | 0.101  |
| 22   | -0.174 | 0.101  | -0.194 | 0.052  | -0.243 | 0.065  | -0.218 | 0.126  |
| 23   | -0.146 | 0.039  | -0.151 | 0.000  | -0.201 | 0.000  | -0.194 | 0.052  |
| 24   | -0.194 | 0.052  | -0.201 | 0.000  | -0.251 | 0.000  | -0.243 | 0.065  |
| 25   | -0.151 | 0.000  | -0.146 | -0.039 | -0.194 | -0.052 | -0.201 | 0.000  |
| 26   | -0.201 | 0.000  | -0.194 | -0.052 | -0.243 | -0.065 | -0.251 | 0.000  |
| 27   | -0.146 | -0.039 | -0.131 | -0.075 | -0.174 | -0.101 | -0.194 | -0.052 |

|    |        |        |        |        |        |        |        |        |
|----|--------|--------|--------|--------|--------|--------|--------|--------|
| 28 | -0.194 | -0.052 | -0.174 | -0.101 | -0.218 | -0.126 | -0.243 | -0.065 |
| 29 | -0.131 | -0.075 | -0.107 | -0.107 | -0.142 | -0.142 | -0.174 | -0.101 |
| 30 | -0.174 | -0.101 | -0.142 | -0.142 | -0.178 | -0.178 | -0.218 | -0.126 |
| 31 | -0.107 | -0.107 | -0.075 | -0.131 | -0.101 | -0.174 | -0.142 | -0.142 |
| 32 | -0.142 | -0.142 | -0.101 | -0.174 | -0.126 | -0.218 | -0.178 | -0.178 |
| 33 | -0.075 | -0.131 | -0.039 | -0.146 | -0.052 | -0.194 | -0.101 | -0.174 |
| 34 | -0.101 | -0.174 | -0.052 | -0.194 | -0.065 | -0.243 | -0.126 | -0.218 |
| 35 | -0.039 | -0.146 | 0.000  | -0.151 | 0.000  | -0.201 | -0.052 | -0.194 |
| 36 | -0.052 | -0.194 | 0.000  | -0.201 | 0.000  | -0.251 | -0.065 | -0.243 |
| 37 | 0.000  | -0.151 | 0.039  | -0.146 | 0.052  | -0.194 | 0.000  | -0.201 |
| 38 | 0.000  | -0.201 | 0.052  | -0.194 | 0.065  | -0.243 | 0.000  | -0.251 |
| 39 | 0.039  | -0.146 | 0.075  | -0.131 | 0.101  | -0.174 | 0.052  | -0.194 |
| 40 | 0.052  | -0.194 | 0.101  | -0.174 | 0.126  | -0.218 | 0.065  | -0.243 |
| 41 | 0.075  | -0.131 | 0.107  | -0.107 | 0.142  | -0.142 | 0.101  | -0.174 |
| 42 | 0.101  | -0.174 | 0.142  | -0.142 | 0.178  | -0.178 | 0.126  | -0.218 |
| 43 | 0.107  | -0.107 | 0.131  | -0.075 | 0.174  | -0.101 | 0.142  | -0.142 |
| 44 | 0.142  | -0.142 | 0.174  | -0.101 | 0.218  | -0.126 | 0.178  | -0.178 |
| 45 | 0.131  | -0.075 | 0.146  | -0.039 | 0.194  | -0.052 | 0.174  | -0.101 |
| 46 | 0.174  | -0.101 | 0.194  | -0.052 | 0.243  | -0.065 | 0.218  | -0.126 |
| 47 | 0.146  | -0.039 | 0.151  | 0.000  | 0.201  | 0.000  | 0.194  | -0.052 |
| 48 | 0.194  | -0.052 | 0.201  | 0.000  | 0.251  | 0.000  | 0.243  | -0.065 |

BISTATIC PATTERN: PHI INCIDENT (DEG) = 0.00

PHI S(DEG) ECHO WIDTH(M) ECHO WIDTH(DB/M) |FIELD| PHASE(DEG)

|       |        |         |       |       |
|-------|--------|---------|-------|-------|
| 0.00  | 0.3751 | -4.2581 | 0.244 | 20.77 |
| 5.00  | 0.3767 | -4.2403 | 0.245 | 21.40 |
| 10.00 | 0.3817 | -4.1827 | 0.246 | 23.28 |
| 15.00 | 0.3913 | -4.0744 | 0.250 | 26.30 |
| 20.00 | 0.4072 | -3.9024 | 0.255 | 30.28 |
| 25.00 | 0.4307 | -3.6580 | 0.262 | 34.94 |
| 30.00 | 0.4632 | -3.3420 | 0.272 | 40.02 |
| 35.00 | 0.5049 | -2.9682 | 0.283 | 45.22 |
| 40.00 | 0.5545 | -2.5607 | 0.297 | 50.32 |
| 45.00 | 0.6095 | -2.1504 | 0.311 | 55.18 |
| 50.00 | 0.6653 | -1.7696 | 0.325 | 59.71 |
| 55.00 | 0.7163 | -1.4492 | 0.338 | 63.91 |
| 60.00 | 0.7555 | -1.2174 | 0.347 | 67.82 |
| 65.00 | 0.7762 | -1.1001 | 0.351 | 71.49 |
| 70.00 | 0.7722 | -1.1227 | 0.351 | 75.02 |
| 75.00 | 0.7391 | -1.3132 | 0.343 | 78.52 |
| 80.00 | 0.6754 | -1.7045 | 0.328 | 82.15 |
| 85.00 | 0.5834 | -2.3401 | 0.305 | 86.14 |
| 90.00 | 0.4699 | -3.2804 | 0.273 | 90.87 |

|        |        |          |       |         |
|--------|--------|----------|-------|---------|
| 95.00  | 0.3458 | -4.6114  | 0.235 | 97.06   |
| 100.00 | 0.2267 | -6.4448  | 0.190 | 106.24  |
| 105.00 | 0.1313 | -8.8189  | 0.145 | 122.00  |
| 110.00 | 0.0799 | -10.9752 | 0.113 | 151.29  |
| 115.00 | 0.0930 | -10.3134 | 0.122 | -169.70 |
| 120.00 | 0.1888 | -7.2411  | 0.173 | -143.21 |
| 125.00 | 0.3804 | -4.1975  | 0.246 | -129.33 |
| 130.00 | 0.6746 | -1.7097  | 0.328 | -121.47 |
| 135.00 | 1.0693 | 0.2910   | 0.413 | -116.50 |
| 140.00 | 1.5533 | 1.9125   | 0.497 | -113.10 |
| 145.00 | 2.1057 | 3.2339   | 0.579 | -110.65 |
| 150.00 | 2.6973 | 4.3093   | 0.655 | -108.82 |
| 155.00 | 3.2925 | 5.1753   | 0.724 | -107.45 |
| 160.00 | 3.8524 | 5.8573   | 0.783 | -106.42 |
| 165.00 | 4.3377 | 6.3726   | 0.831 | -105.67 |
| 170.00 | 4.7133 | 6.7332   | 0.866 | -105.16 |
| 175.00 | 4.9509 | 6.9468   | 0.888 | -104.87 |
| 180.00 | 5.0322 | 7.0176   | 0.895 | -104.77 |
| 185.00 | 4.9512 | 6.9471   | 0.888 | -104.88 |
| 190.00 | 4.7140 | 6.7339   | 0.866 | -105.18 |
| 195.00 | 4.3387 | 6.3736   | 0.831 | -105.70 |
| 200.00 | 3.8536 | 5.8586   | 0.783 | -106.46 |
| 205.00 | 3.2939 | 5.1771   | 0.724 | -107.50 |
| 210.00 | 2.6987 | 4.3116   | 0.655 | -108.89 |
| 215.00 | 2.1072 | 3.2370   | 0.579 | -110.74 |
| 220.00 | 1.5548 | 1.9168   | 0.497 | -113.22 |
| 225.00 | 1.0708 | 0.2973   | 0.413 | -116.65 |
| 230.00 | 0.6761 | -1.6998  | 0.328 | -121.67 |
| 235.00 | 0.3820 | -4.1795  | 0.247 | -129.60 |
| 240.00 | 0.1904 | -7.2034  | 0.174 | -143.56 |
| 245.00 | 0.0948 | -10.2316 | 0.123 | -170.02 |
| 250.00 | 0.0818 | -10.8708 | 0.114 | 151.35  |
| 255.00 | 0.1334 | -8.7479  | 0.146 | 122.28  |
| 260.00 | 0.2292 | -6.3988  | 0.191 | 106.53  |
| 265.00 | 0.3485 | -4.5779  | 0.236 | 97.32   |
| 270.00 | 0.4728 | -3.2533  | 0.274 | 91.10   |
| 275.00 | 0.5866 | -2.3166  | 0.306 | 86.35   |
| 280.00 | 0.6787 | -1.6832  | 0.329 | 82.35   |
| 285.00 | 0.7425 | -1.2932  | 0.344 | 78.70   |
| 290.00 | 0.7756 | -1.1037  | 0.351 | 75.19   |
| 295.00 | 0.7795 | -1.0817  | 0.352 | 71.66   |
| 300.00 | 0.7586 | -1.1997  | 0.347 | 67.99   |
| 305.00 | 0.7191 | -1.4323  | 0.338 | 64.08   |
| 310.00 | 0.6678 | -1.7538  | 0.326 | 59.88   |

|        |        |         |       |       |
|--------|--------|---------|-------|-------|
| 315.00 | 0.6115 | -2.1358 | 0.312 | 55.35 |
| 320.00 | 0.5562 | -2.5479 | 0.298 | 50.49 |
| 325.00 | 0.5061 | -2.9575 | 0.284 | 45.39 |
| 330.00 | 0.4641 | -3.3337 | 0.272 | 40.17 |
| 335.00 | 0.4313 | -3.6520 | 0.262 | 35.09 |
| 340.00 | 0.4075 | -3.8986 | 0.255 | 30.40 |
| 345.00 | 0.3915 | -4.0723 | 0.250 | 26.40 |
| 350.00 | 0.3818 | -4.1817 | 0.247 | 23.35 |
| 355.00 | 0.3767 | -4.2399 | 0.245 | 21.43 |
| 360.00 | 0.3751 | -4.2581 | 0.244 | 20.77 |

TOTAL CPU TIME= 316.19 SEC